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AN OVERVIEW OF WATER QUALITY IN THE RED DEER RIVER BASIN (1983-1984)

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OVERVIEW

This report provides an overview of water quality in the Red Deer River as determined during intensive surveys conducted between April 1983 and March 1984. Samples were collected from 12 mainstream sites, 9 tributaries, and 4 irrigation return flows. Sampling frequency was based on discharge patterns, and varied from two week intervals during spring, to six week intervals during winter. Data were collected for physical and chemical variables in the water column; biological variables (algae, macrophytes and zoobenthos); and sediment variables (metal and organic contaminants).

The Red Deer River study sites were distributed over four ecoregions (foothills, aspen parkland, mixed grass, and short grass), and the general water quality characteristics reflect the transition in soils, climate and vegetation which occurred. The major anthropogenic effects were the Dickson Dam, treated sewage discharges from the larger urban centers and unquantified activities in the watersheds of several tributaries.

The Red Deer River is an alkaline, hard water system dominated by calcium and bicarbonate. Suspended solids, as indicated by non-filterable residue (NFR) and turbidity, decreased below the Dickson Dam, reflecting retention and sedimentation in the reservoir. However, very large and progressive increases in NFR occurred as the river traversed the highly erodable substrates of the lower basin (badlands). As a consequence, all water quality variables related to the particulate phase followed similar patterns.

Dissolved solids also increased in the lower basin reflecting the progressively more saline nature of tributaries and irrigation return flows in those reaches. Nutrients and coliform bacteria were significantly increased as a consequence of treated sewage discharges below Red Deer and Drumheller. Benthic algal standing crops increased below Red Deer but declined thereafter, possibly reflecting the combined effects of dissolved P depletion, increased turbidity in the lower reaches, and substrate changes.

The zoobenthos in the Red Deer River also reflected the gradual changes in physical characteristics which occur along the river. Insect larvae such as mayflies and stoneflies were more prevalent and more diverse in erosional habitats (i.e., rocky substrate, swift water flow) which typify the upper reaches of the river; burrowing organisms such as midges and worms became more important in downstream direction as the river became increasingly depositional in nature (i.e., silty, sandy substrates, slow water flow).

Man's activities also influenced the distribution of zoobenthos along the river. A notable increase in invertebrate numbers and biomass (wet weight) was observed downstream of the city of Red Deer as a result of the enrichment by treated sewage discharges.

In the first fall after the completion of Dickson Dam, invertebrates were more numerous at sites between the dam and the city of Red Deer than above the dam site. In spring, before the completion of the dam, no such difference was observed.

Certain water quality constituents in the Red Deer River exceeded the objective levels defined by the Alberta Surface Water Quality Objectives (ASWQO). Bacterial populations frequently exceeded the contact recreation objectives below Red Deer, Drumheller, and Jenner. Bacterial water quality was also poor in several lower tributaries (Rosebud, Kneehills Matzhiwin, Onetree). Dissolved oxygen concentrations met ASWQO in the mainstream but fell below the 5.0 mg/L objective in the upper tributaries (Little Red Deer, Medicine, Blindman) during winter. Total phosphorus exceeded ASWQO throughout the system, frequently below Red Deer and most frequently below Jenner and in tributaries. Exceedences in tributaries were high for phosphorus and nitrogen. Iron exceeded ASWQO in the upper tributaries and mainstream but exceeded objectives most frequently downstream. More metal data are required for the middle and lower reaches of the Red Deer River in order to complete the evaluation, but the high, natural inorganic turbidity doubtlessly contributes to high, total metal concentrations.

A full analysis of the impact of the Dickson Dam on water quality and zoobenthos of the Red Deer River for the period 1983-1987 is available in Shaw and Anderson (1991).

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1.0 INTRODUCTION

There are three basic components to the strategy for surface water quality monitoring in southern Alberta. The first provides the basic framework. It consists of routine chemical monitoring at selected river locations for identification of long-term trends, and continuous remote automatic monitoring at key points on the major rivers to detect spill events. The second component consists of an intensive monitoring program for each major river on a rotational basis. The final component consists of short-term, more site-specific sampling to address specific water quality questions.

This study of the Red Deer River represents the second component of the overall monitoring strategy. It provides additional chemical monitoring of the river and its tributaries; biological monitoring of the algae, macrophytes, and benthic invertebrates; and testing of sediments for accumulation of metals and organic contaminants.

The Red Deer River was chosen for intensive study in 1983-84 for several reasons. First, the Red Deer River underwent a major change that year with the start-up of the Dickson Dam. Monitoring the effects of the dam on the river was particularly important. In fact, a study of the reservoir was carried out to coordinate with river studies. Second, industrial development in the river basin is expected to increase in the future and current baseline conditions should be established. Third, tributary streams have been identified as having a significant effect on the river, and therefore, they should be monitored. Fourth, a database for the computer model WQRRS, which has been developed for the basin, was necessary for calibration and model development. The sampling program

addressed each of these requirements.

The establishment of a thorough database for the Red Deer River complements the studies carried out on the other three rivers in the southern basin (Cross et al., 1986; Charlton et al., 1986). Similarities and differences were investigated. In addition, the 1983-84 database can be compared to historical data for the Red Deer River and water quality objective criteria.

Perceived as one of the major problems with water quality in the Red Deer River is the annual reduction in dissolved oxygen under winter ice cover (Chapman, 1972). River and sewage inputs have been monitored since 1958 for dissolved oxygen, biochemical oxygen demand, and chemical oxygen demand (Hrabar, 1974). This chronic problem became so acute that in the winter of 1971-72, a U-tube aerator was installed in the river until upgrading of sewage treatment facilities was completed. This upgrading reduced the input of oxygen-demanding effluents. Studies of the upstream tributaries of the Red Deer River by Baker et al. (1976), Baker (1978) and Baker et al. (1982) identified natural organic inputs as having an important influence on the extent of winter oxygen depletion in the river.

One function of the Dickson Dam, with respect to water quality, was the augmentation of winter flows (Alberta Environment, 1975). Calculations were made to determine the flow required to maintain winter dissolved oxygen values above 5 $mg \cdot L^{-1}$ along the length of the river (Grant, 1973). This sampling program included an investigation of the effects of the first winter of flow augmentation on dissolved oxygen. However, several years' data are required to fully evaluate the efficacy of flow augmentation.

The Dickson Dam will affect other aspects of water quality (Baxter and Glaude, 1980), as well as the biological community (Ward, 1976). The initial effects will be monitored, but a full discussion of the downstream effects of the dam will be reserved until several years of data on both the reservoir and the river are collected.

2.0 METHODS

2.1 SAMPLING SITES AND FREQUENCY OF SAMPLING

The Red Deer River study area extended 625 km from the first sampling site above the Dickson Dam to the confluence of the Red Deer River with the South Saskatchewan River (Figure 1). Long-term monitoring within this portion of the basin was maintained through monthly water quality sampling at Red Deer, Drumheller, and Bindloss and remote continuous monitoring at Drumheller. Sampling sites for this study were established at 12 mainstem river sites and 13 tributary and irrigation return flow points (Figure 1, Table 1).

The study was conducted from April 1983 to March 1984. Sampling frequency was designed to emphasize the higher discharge periods during which water quality characteristics change more rapidly. Thus, the Red Deer River and its major tributaries were sampled throughout the year: once every two weeks from April to July, once every three weeks from August to October, and three times from November to March. Ephemeral streams were sampled only in the spring and irrigation return flows were sampled throughout the growing season.

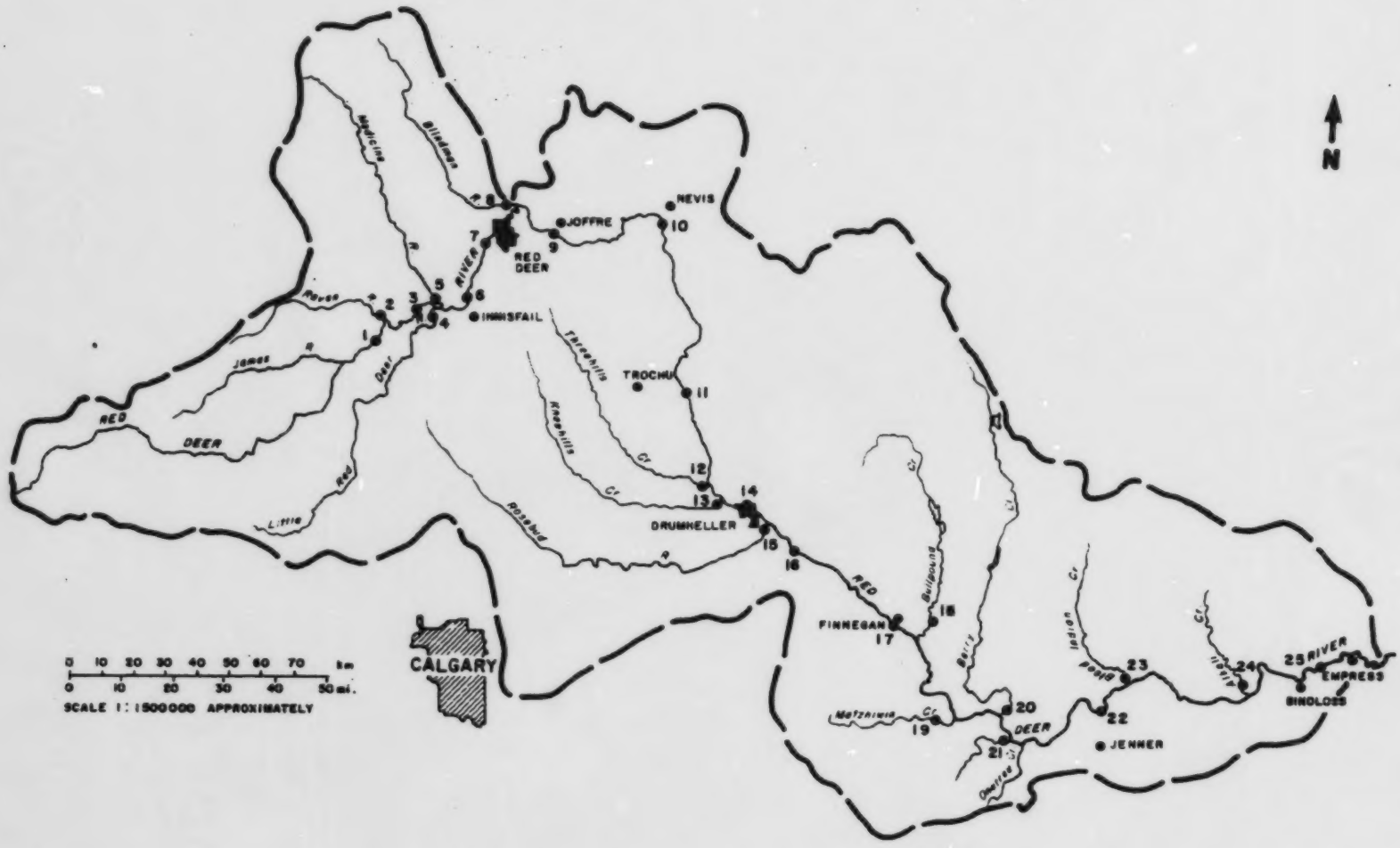

FIGURE I. RED DEER RIVER SAMPLING SITES

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Table 1. Locations of and NAQUADAT codes for Red Deer River study sampling sites.

SITE	NAQUADAT CODE	RIVER DISTANCE (KM)	LOCATION
1	00AL05CB0600	634	Red Deer River above Dickson Dam
2	00AL05CB1250	606	Raven River
3	00AL05CC1000	580	Red Deer River below Dickson Dam
4	00AL05CB1700	574	Little Red Deer River
5	00AL05CC1620	571	Medicine River
6	00AL05CC1700	561	Red Deer River near Innisfail
7	00AL05CC1800	533	Red Deer River above Red Deer
8	00AL05CC2085	507	Blindman River
9	00AL05CD1000	488	Red Deer River below Red Deer
10	00AL05CD1200	440	Red Deer River near Nevis
11	00AL05CD1300	375	Red Deer River near Trochu
12	00AL05CD2800	336	Threehills Creek
13	00AL05CD3000	330	Kneehills Creek
14	00AL05CE1000	319	Red Deer River above Drumheller
15	00AL05CE2125	311	Rosebud River
16	00AL05CE2135	296	Red Deer River below Drumheller
17	00AL05CG2000	255	Red Deer River near Finnegan
18	00AL05CG3000	307	Bullpound Creek
19	00AL05CJ2100	204	Matzhiwin Creek
20	00AL05CH3000	186	Berry Creek
21	00AL05CJ1000	178	Onetree Creek
22	00AL05CJ3000	136	Red Deer River near Jenner
23	00AL05CK1000	122	Blood Indian Creek
24	00AL05CK1200	73	Alkali Creek
25	00AL05CK3000	20	Red Deer River near Alta. - Sask. border
		0	Red Deer River at mouth

2.2 PHYSICAL AND CHEMICAL PARAMETERS

In general, samples were collected at each site after walking into the river to depths no greater than 0.5 m. Light penetration at the surface and bottom of the water (Protomatic photometer), dissolved oxygen (Hydrolab oxygen meter calibrated daily using Winkler Titration), and water and air (shaded) temperatures (Fisher Brand 15-021B hand thermometer) were measured. Site characteristics and percent cloud cover were noted. Samples for metals analysis were collected only at three river sites: above and below the Dickson Dam and upstream of the City of Red Deer.

Water samples were collected in triple-rinsed sample bottles and were shipped daily to the Alberta Environmental Center in Vegreville for analysis using methods described in Table 2. From August until completion of the study, biochemical oxygen demand was determined for only eight sites to reduce excessive analytical processing time.

Bacteriological samples were shipped on ice within 24 hours of collection for analysis at the Public Health Laboratory in Calgary. Samples were analyzed using membrane filtration. Sampling was reduced from 25 to eight sites from October to the end of the study to accommodate laboratory quotas.

Dissolved oxygen at the site downstream of Red Deer was monitored for 24 hours on two occasions (July 27-28 and September 8-9, 1983). Measurements were taken every hour and the meter was calibrated every eight hours.

Using a Ryan's thermograph, temperatures were monitored continuously at the site downstream of the Dickson Dam from August 16 to

Table 2. NAQUADAT codes for water chemistry variables sampled during the study.

VARIABLE	NAQUADAT CODE	VARIABLE	NAQUADAT CODE
Total dissolved solids	00205L	Silica - reactive	14102L
Specific conductance	02041L	Phosphorus - dissolved	15105L
Temperature - water	02061F	- diss. reactive	15256L
- air	02066F	- total	15421L
Turbidity	02073L	- particulate	15901L
Carbon - diss. organic	06107L	Sulphate - dissolved	16306L
- diss. inorganic	06154L	Chloride - dissolved	17203L
- particulate	06905L	Potassium - dissolved	19103L
Bicarbonate - dissolved	06202L	Calcium - dissolved	20110L
Carbonate - dissolved	06302L	Coliforms - total	36001L
Phenolic material	06537L	- fecal	36011L
Chlorophyll - phytoplankton	06720L	Metals - extract.- beryllium	04304L
- epilithon	06721L	- magnesium	12303L*
Nitrogen - diss. Kjeldahl	07017L	- aluminum	13306L
- total Kjeldahl	07021L	- iron	26304L
- nitrate + nitrite	07111L	- lead	82302L
- nitrite	07206L	- total - vanadium	23009L
- diss. ammonia	07562L	- chromium	24009L
- particulate	07906L	- manganese	25003L
Oxygen - dissolved	08102F	- cobalt	27009L
Chemical Oxygen Demand	08301L	- nickel	28009L
Biochemical Oxygen Demand	08202L	- copper	29009L
Fluoride - dissolved	09107L	- zinc	30009L
Alkalinity - total	10101L	- arsenic	33005L
pH	10301L	- selenium	34005L
Residue - non-filterable	10407L	- molybdenum	42009L
Hardness - total	10602L	- cadmium	48009L
Sodium - dissolved	11103L	- mercury	80015L

* Input code 12102L used for NAQUADAT storage to accommodate hardness calculation

November 14, 1983 .

Sediment samples were collected in mid-November 1983 at seven mainstem river sites using an airlift sampler. The sediment slurry was allowed to settle for at least 24 hours before the supernatant was decanted. The sediment was then transferred to xylene-washed glass jars and shipped to Vegreville for analysis.

2.3 ALGAE AND MACROPHYTES

Benthic algae and phytoplankton samples, with the exception of benthic algae in winter, were collected at mainstem river sites on each trip. At tributary and irrigation return flow sites, phytoplankton samples were taken every second trip.

Phytoplankton chlorophyll a was collected by filtering (in the shade) 1 litre of water through a 5.5 cm Whatman GFC filter. Each sample was preserved with magnesium carbonate, wrapped in tin foil, and stored on dry ice. The filtrate from these samples was filtered through a 0.45μ Sartorius membrane filter for low-level nutrient determinations.

For benthic algal chlorophyll a determination, algae was brushed from a maximum of 10 rocks and collected. It was then added to distilled water and the volume of the resultant slurry of algae and distilled water was measured and a subsample was taken using a wide-mouth 50 cc syringe. The subsample was filtered and preserved in the same manner as were the phytoplankton samples. When abundance and matting of algae in late spring made sampling difficult, algae samples were taken from single rather than numerous rocks.

Macrophytes were not sampled because they were scarce at

mainstem river sites.

2.4 BENTHIC INVERTEBRATES

Benthic invertebrates were sampled at all mainstem river sites from April 15 to 22, 1983 and from September 19 to October 7, 1983. In general, samples were collected in riffles at a depth ranging between 0.3 and 0.5 m. The amount of silt covering the substrate became increasingly important at downstream sites and was dominant at Jenner and Empress. Because the Neill cylinder is inadequate for sampling silt, sampling was discontinued at Jenner in the fall.

At each site, 5 Neill cylinder samples (area sampled = 0.1 m^2) were collected and filtered through a 210μ mesh collecting net. Larger stones were removed and cleaned by gentle rubbing and rinsing in the cylinder and a narrow shovel was used to disturb the substrate for approximately one minute.

Samples were preserved in 4% formaldehyde immediately following collection. They were later stained with Rose Bengal (Mason and Yevich, 1967) and sorted in the laboratory using a dissecting microscope with magnifications of 6 to 25 (objective) X 10 (ocular). Invertebrates were counted and identified according to Bauman et al. (1977), Edmunds et al. (1976), Merritt and Cummins (1979), Pennak (1953), and Wiggins (1977).

The wet weight of each sample was measured using a Mettler H51 balance (precision 0.0001 g) after the excess water had been blotted from the invertebrate specimens.

2.5 STATISTICAL ANALYSES

Dissolved phosphorus loading was calculated from phosphorus concentration and discharge data as the average of the following two formulae:

$$L_1 = \frac{\Sigma c_i q_i}{\Sigma q_i} \cdot k\, Q \qquad L_2 = \frac{\Sigma c_i q_i}{n} \cdot k$$

where L = loading in tonnes

c_i = instantaneous concentration in $mg \cdot L^{-1}$

q_i = mean daily discharge in $m^3 \cdot s^{-1}$

n = number of observations of both variables

Q = mean discharge in $m^3 \cdot s^{-1}$

k = constant for unit adjustment

The two formulae were averaged because each is an acceptable calculation for use with both instantaneous and daily data, but because of discharge information, results can vary.

Using SPSS (Nie et al., 1975), Pearson's correlations using SPSS were calculated for discharge, turbidity, non-filterable residue, particulate carbon, total phosphorus, particulate nitrogen, and total Kjeldahl nitrogen. Using SPSS^x (SPSS Inc., 1983), principal components or factor analysis was carried out on the chemistry data set to determine the set of components that account for the observed interrelations in the data. Variables from data sets that did not have a normal distribution were $\log_1(x+1)$ transformed before analysis. Pairwise deletion of missing values was used to include as many cases as possible in the analysis.

Cluster analysis (CLUSTAN; Wishart, 1978) and principal components analysis (SPSS*) were performed separately on the spring and fall benthic invertebrate data sets. Erratically occurring taxa were eliminated from the data set and the mean number of taxa per site was transformed to log(x+1) prior to analysis. The similarity index used in cluster analysis is Euclidean distance and the Ward (1963) method was used for the fusion of similar clusters.

The Shannon Wiener diversity (Shannon and Wiener, 1949) was calculated according to:

$$H' = \sum_{i=1}^{n} p_i \ln p_i$$

where $p_i = \frac{n_i}{N}$

n_i = numbers (density) for taxon i

N = total numbers

n = total number of taxa

3.0 RESULTS

Some overall generalities can be made about water quality results from this study. First, concentrations measured in spring and early July were often higher than at other times. These were also the times of greater discharge. Second, the change in trends for different parameters often occurred at the same locations along the river . This suggested a natural division of the river into different reaches. These divisions occurred below the Dickson Dam, at Red Deer, above Drumheller, and below Finnegan. Seasonal results from sites representative of these reaches are presented in this report.

The water quality in the tributaries of the upper reaches of the river was quite often different from that in the tributaries entering the lower reaches. To some extent, these findings resulted from the fact that tributaries were grouped and sampled on different schedules, and average concentrations were calculated from these samples regardless of seasonal bias. This is not enough, however, to account for all differences in water quality. Natural differences would occur because the tributaries originate in different geographical zones (e.g. foothills versus plains).

3.1 PHYSICAL CONDITIONS

3.1.1 Discharge

Discharges measured in this study are compared with those from historical information from two sites on the Red Deer River (Figure 2). Historical monthly mean data show peak flows in June at Red Deer and in April and June/July at Bindloss. Discharges measured in 1983 were very low in June, and in general, were lower than average. This was the first year of flow regulation at the Dickson Dam.

3.1.2 Water Temperature

Seasonal fluctuations in water temperature in the Red Deer River, as illustrated by data from the remote monitor at Drumheller, are primarily controlled by climate (Figure 3). Temperatures were low in winter and maximum values as high as 25.8°C were measured in August. The large range of values measured in April and September indicate seasonal warming and cooling, respectively. Temperatures in the upstream reaches

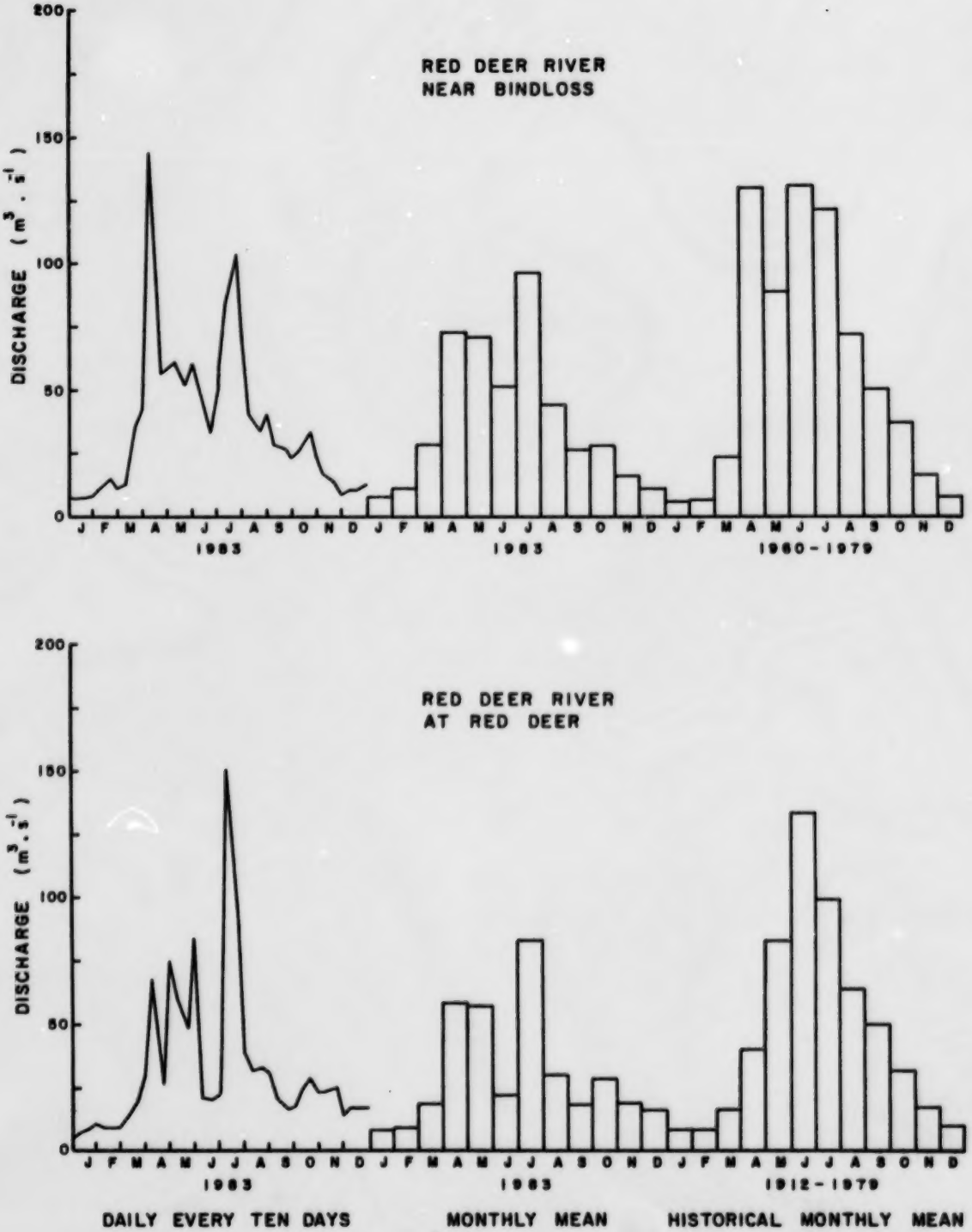
RED DEER RIVER
NEAR BINDLOSS
DISCHARGE ($m^3 . s^{-1}$)
200
150
100
50
0
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1983
1983
1960 - 1979
RED DEER RIVER
AT RED DEER
DISCHARGE ($m^3 . s^{-1}$)
200
150
100
50
0
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1983
1983
1912 - 1979
DAILY EVERY TEN DAYS
MONTHLY MEAN
HISTORICAL MONTHLY MEAN

Figure 2. DISCHARGE IN THE RED DEER RIVER

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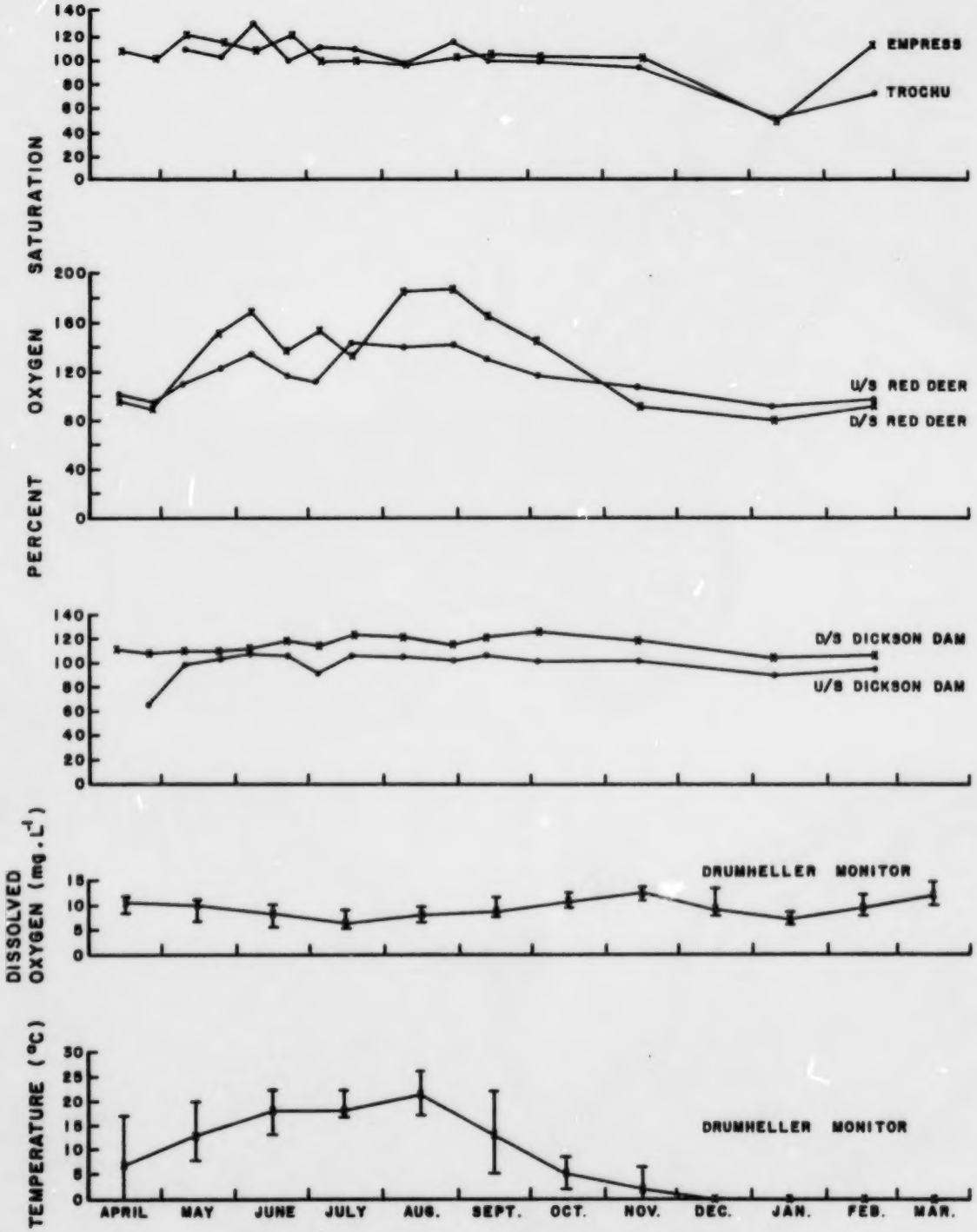

Figure 3. TEMPERATURE AND DISSOLVED OXYGEN IN THE RED DEER RIVER

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of a river are generally expected to be lower than those in the downstream reaches.

A secondary degree of temperature fluctuation, the change over a single day, is illustrated by data from the remote monitor at Drumheller (Figure 4a). This diurnal fluctuation was also measured at a site downstream of the Dickson Dam to monitor the effects of the dam. The thermograph recorded a slight warming from August 16 to September 9, with temperatures fluctuating approximately 1.5°C, from 14.5 to 16°C. Temperatures of 16.5°C were measured on September 1 and 3. From September 9 to October 3, the water cooled, especially in mid-September. Temperatures ranged from 9 to 15°C and fluctuated approximately 2 to 2.5°C in a day. A maximum fluctuation of 3.2°C was measured on September 22. Water temperatures decreased from October 3 to November 4, ranging from 5 to 11°C. Diurnal fluctuations were reduced to about 1°C, even less diurnal fluctuation occurring in mid-October.

3.1.3 Dissolved Oxygen and Oxygen Demand

Monthly average values of dissolved oxygen (D.O.) at Drumheller (Figure 3) were lowest in July (6.6 $mg \cdot L^{-1}$) and January (7.3 $mg \cdot L^{-1}$) and highest in November (12.6 $mg \cdot L^{-1}$) and April (10.3 $mg \cdot L^{-1}$). Diurnal fluctuations in dissolved oxygen concentrations were higher in June and August and lower in February, April, and September (Figure 4b). However, when the controlling effect of temperature is removed by comparing percent saturation, April and September values showed stronger diurnal fluctuations and were more similar to June and August results (Figure 4a).

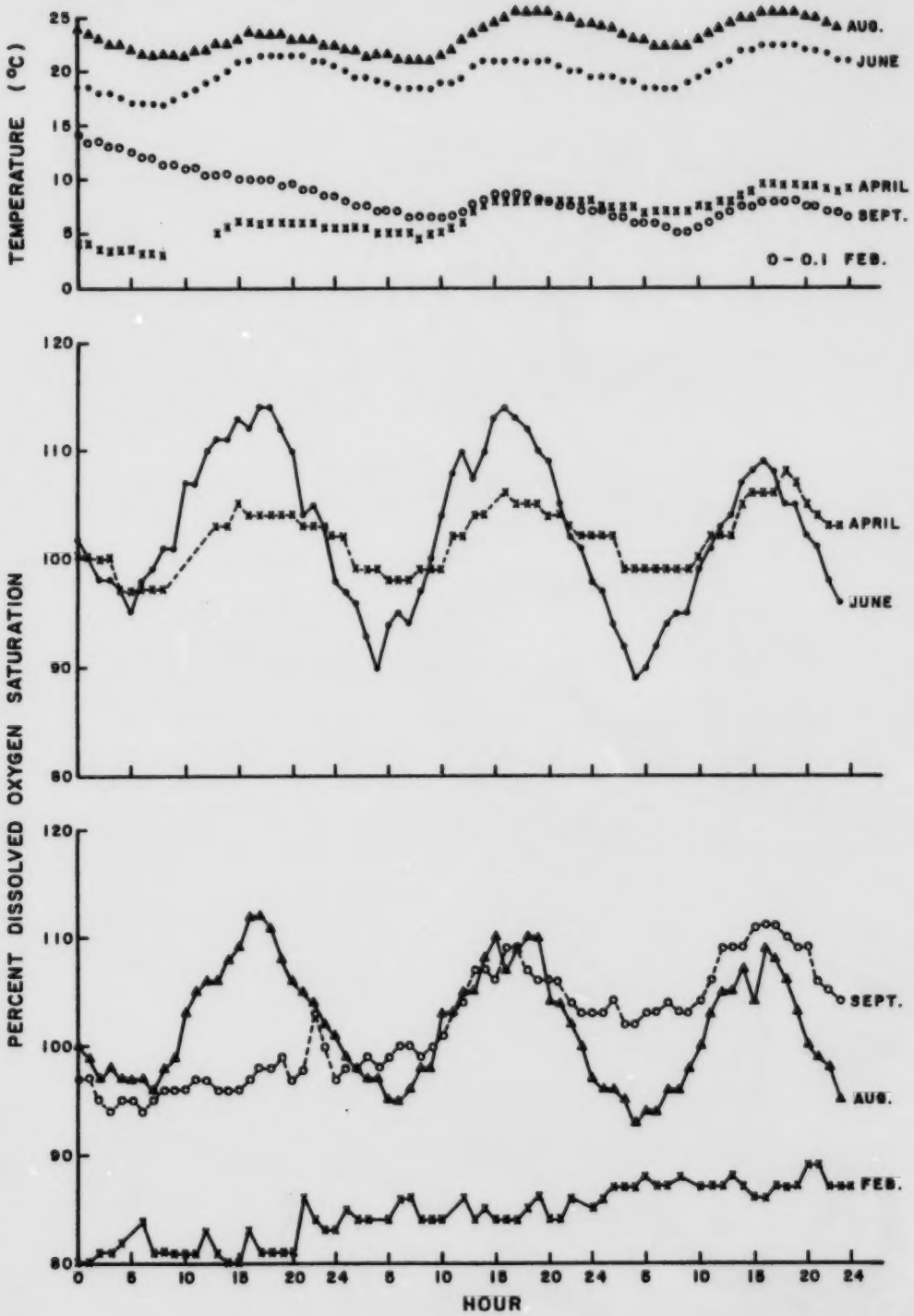

Figure 4a. DIURNAL TEMPERATURE AND PERCENT DISSOLVED OXYGEN SATURATION AT DRUMHELLER.

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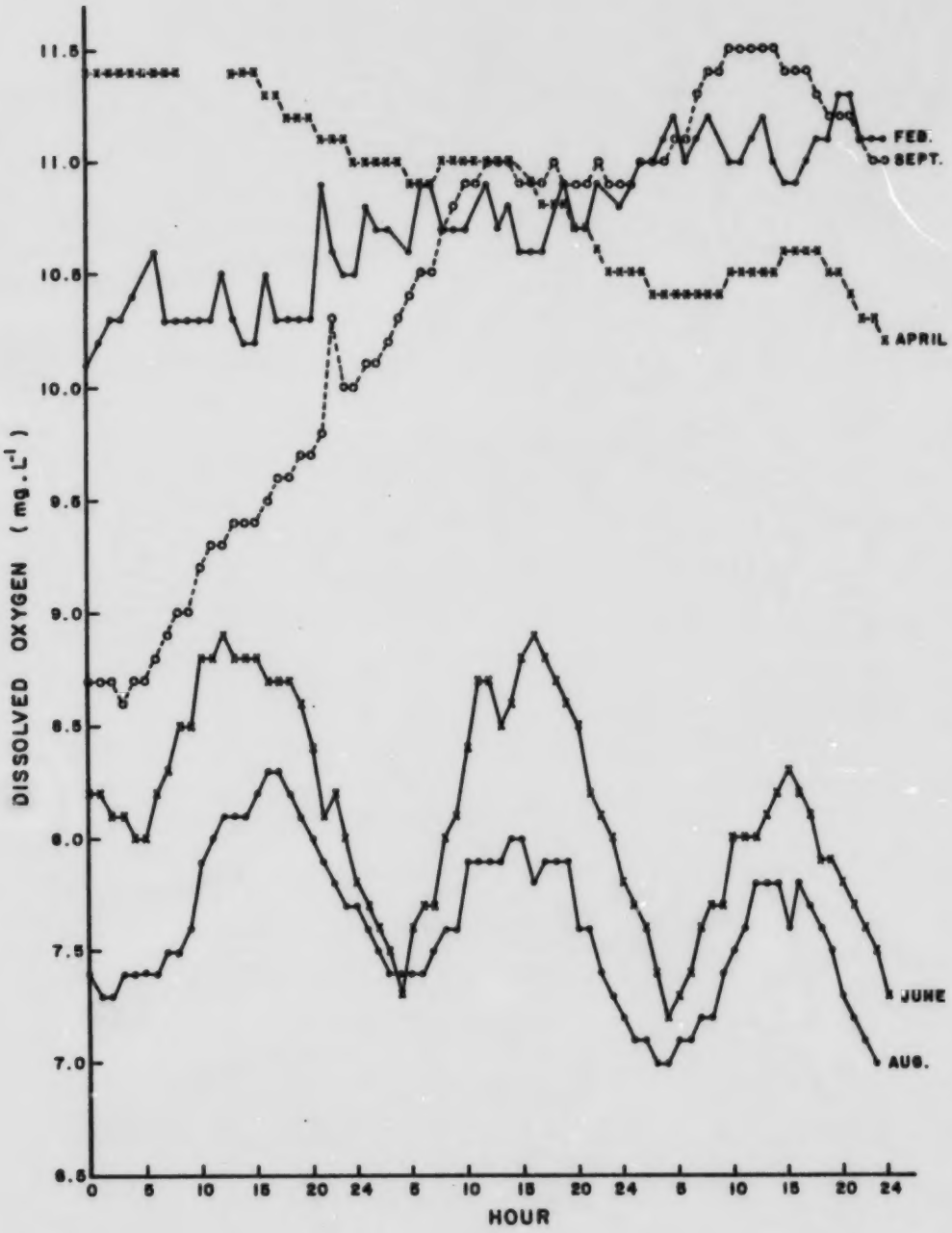

Figure 4b. DIURNAL DISSOLVED OXYGEN AT DRUMHELLER .

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Saturation levels of dissolved oxygen measured on two occasions at the site downstream of Red Deer illustrated strong diurnal fluctuations, from 89% to 141% in July and 78% to 134% in September (Figure 5).

Data collected from each study site are difficult to compare between sites because they are biased by the time of sampling. However, seasonal trend analysis is valid within each site because they were sampled at approximately the same time throughout the study. Figure 3 illustrates the variability in trends along the length of the river.

Dissolved oxygen readings from upstream sites (above and below the Dickson Dam) were more constant throughout the year than were those from sites around Red Deer. The latter sites were sampled in late afternoon, during which time dissolved oxygen concentrations are high. Peaks in dissolved oxygen saturation were measured in June and August. The lowest values for dissolved oxygen saturation were measured in January, particularly in the lower reaches of the Red Deer River from Nevis to Empress.

Dissolved oxygen concentrations in tributary streams follow similar seasonal trends. Extremely low values were measured in January (Figure 6): concentrations in the Little Red Deer, Blindman, and Medicine rivers were less than 5 $mg \cdot L^{-1}$.

Average annual concentrations of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) followed similar trends in the upper reaches of the river (Figure 7). Values decreased from above (Site 1) to below (Site 3) the Dickson Dam, then increased again at Innisfail (Site 6). Downstream values of biochemical oxygen demand increased gradually

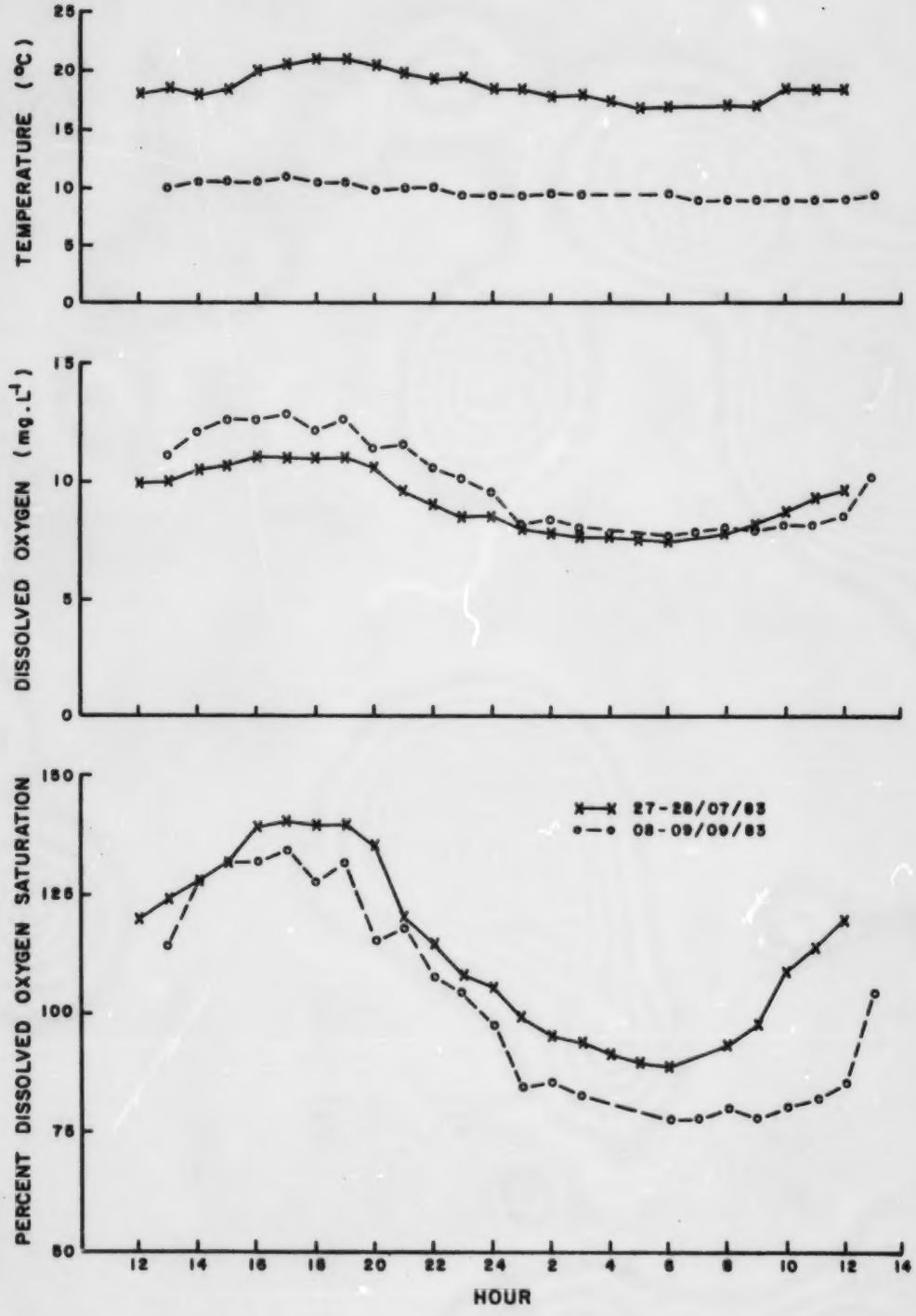

Figure 5. DIURNAL TEMPERATURE AND DISSOLVED OXYGEN DOWNSTREAM OF RED DEER

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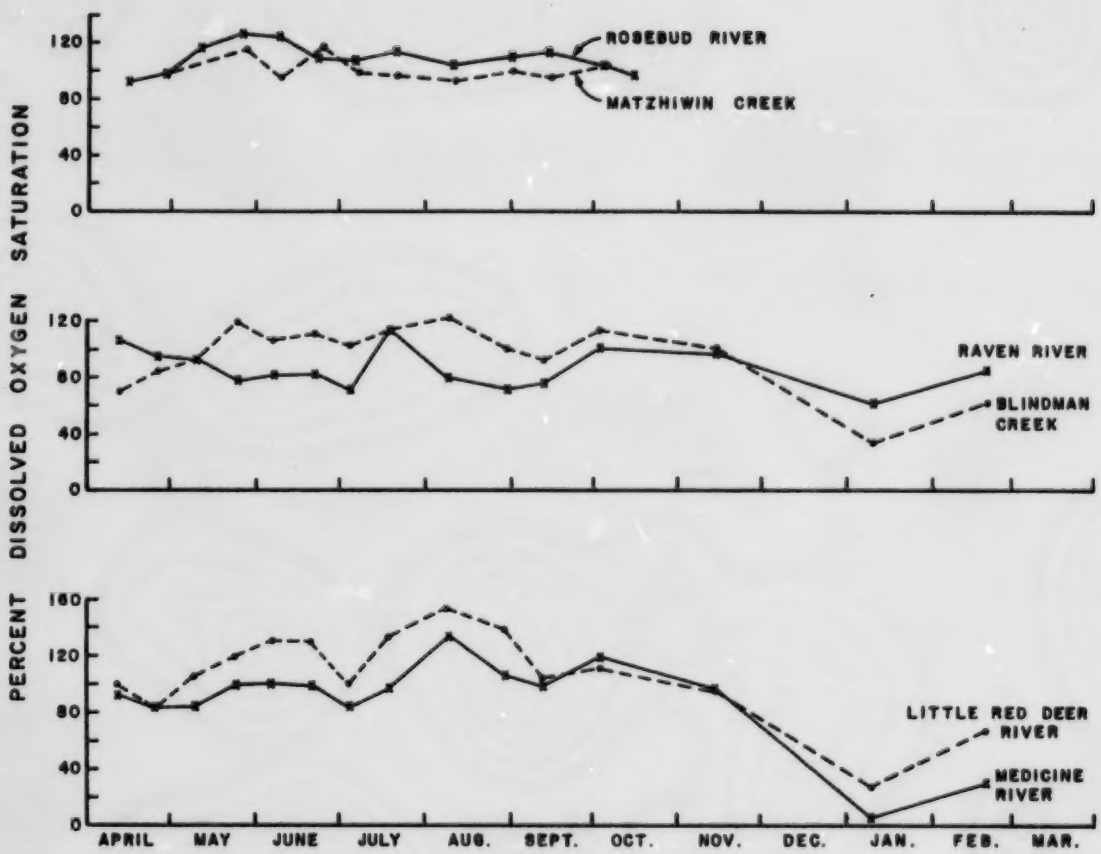

Figure 6. DISSOLVED OXYGEN SATURATION IN TRIBUTARIES OF THE RED DEER RIVER

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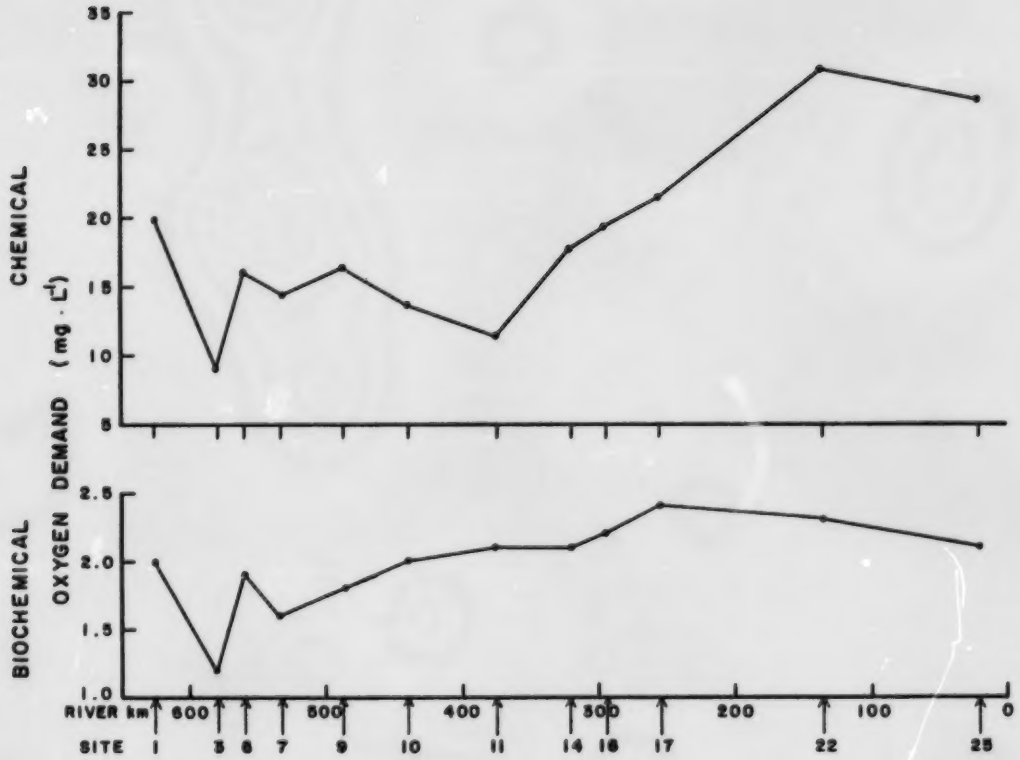

Figure 7. AVERAGE ANNUAL CONCENTRATIONS OF OXYGEN DEMAND AT SITES ALONG THE RED DEER RIVER.

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from above Red Deer (Site 7; 1.6 $mg \cdot L^{-1}$) to Finnegan (Site 17; 2.4 $mg \cdot L^{-1}$) before decreasing slightly near Empress (Site 25; 2.1 $mg \cdot L^{-1}$). The pattern of chemical oxygen demand along the length of the river showed a decrease from below Red Deer (Site 9; 16 $mg \cdot L^{-1}$) to Trochu (Site 11; 11 $mg \cdot L^{-1}$) before increasing rapidly near Jenner (Site 22; 31 $mg \cdot L^{-1}$). There was a slight reduction near Empress (Site 25; 29 $mg \cdot L^{-1}$).

Seasonally, chemical oxygen demand was relatively consistent at all sites with peak demand in April and July and low demand in winter (Figure 8). Biochemical oxygen demand concentrations were less varied over the year, with small peaks in April and July.

Mean annual biochemical oxygen demand values for tributary streams ranged from 1.4 $mg \cdot L^{-1}$ in the Raven River to 3.3 $mg \cdot L^{-1}$ in the Blindman River and Threehills Creek (Table 3). The Little Red Deer River had the widest range of values, from less than 1.0 $mg \cdot L^{-1}$ to 12.1 $mg \cdot L^{-1}$ (April 26, 1983). Chemical oxygen demand followed a similar distribution with mean annual values ranging from 10.7 $mg \cdot L^{-1}$ to 57.9 $mg \cdot L^{-1}$. A maximum of 124.0 $mg \cdot L^{-1}$ was measured in the Little Red Deer River.

3.1.4 Turbidity and Non-Filterable Residue

Turbidity and non-filterable residue values showed significant correlations ($r = 0.60$) when all of the data for the basin were combined. Correlations between non-filterable residue and three particulate-related variables (particulate carbon, total phosphorus, and

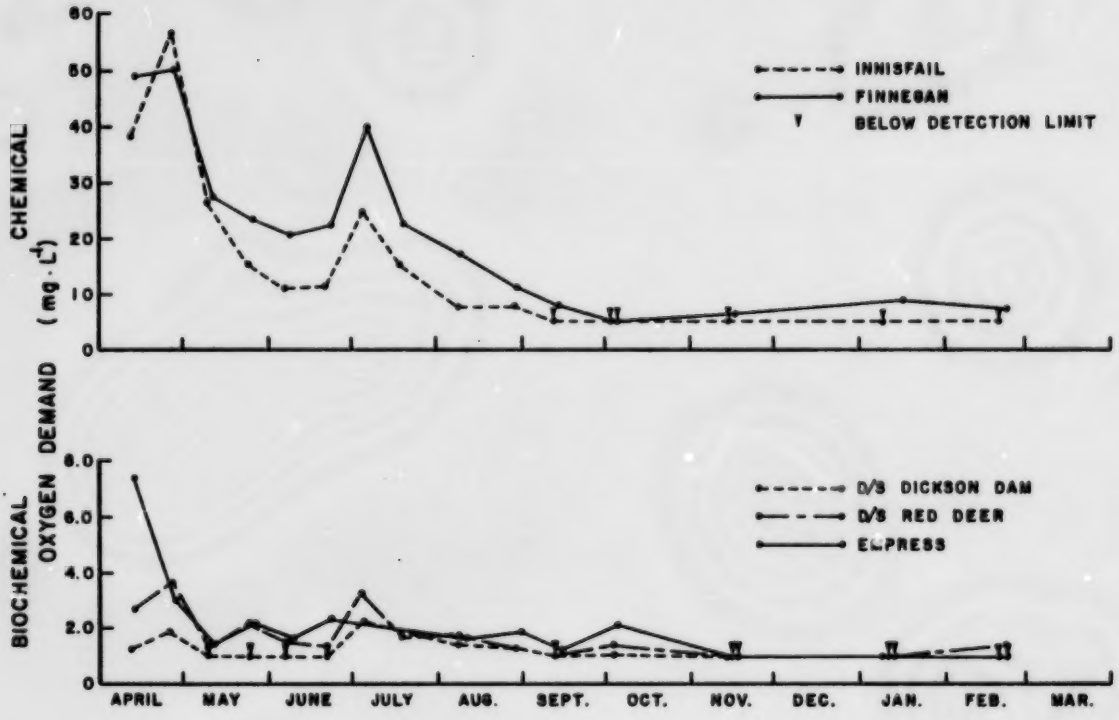

Figure 8. CONCENTRATIONS OF OXYGEN DEMAND AT REPRESENTATIVE SITES ON THE RED DEER RIVER.

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Table 3. Summary of water chemistry data for the major tributaries of the Red Deer River (units are $mg \cdot L^{-1}$, with exceptions noted).

	RAVEN		LITTLE RED DEER		MEDICINE		BLINDMAN		THREEMILLS	
	Mean	Range n=15	Mean	Range n=15	Mean	Range n=15	Mean	Range n=15	Mean	Range n=4
DO	9.1	6.3 - 13.6	10.4	3.6 - 12.7	8.4	0.8 - 12.4	9.1	4.5 - 12.8	11	10.4 - 11.3
COD	10.7	L5 - 24.2	22.7	L5 - 124	40.1	20.8 - 62.5	39.5	16.9 - 61.1	57.9	52.6 - 61.9
BOD	1.4	L1 - 2	2.1	L1 - 12.1	1.8	L1 - 4	3.3	2 - 5.4	3.3	1.9 - 5.3
Turbidity[1]	4.8	1.5 - 15	15.6	L0.1 - 200	4.1	2 - 8.5	4.7	L0.1 - 20	23.8	15 - 40
Conductivity[2]	472	403 - 544	427	286 - 772	495	338 - 992	580	323 - 924	1273	901 - 1487
Na	6	5 - 8	18	11 - 32	32	15 - 72	42	16 - 71	207	144 - 241
Ca	62	50 - 73	46	23 - 89	49	30 - 90	54	8.3 - 93	37	28 - 45
Mg	20	17 - 23	17	11 - 31	18	11 - 33	21	9 - 32	26	19 - 33
K	1.7	1 - 4.1	2.8	1.6 - 4.6	3.5	2.1 - 7.6	4.4	3.3 - 8.3	10.2	9.4 - 11.3
Cl	1	0 - 2	3	2 - 6	3	2 - 5	4	3 - 6	8	7 - 8
SO_4	25	14 - 36	13	10 - 22	16	7 - 32	28	15 - 44	281	185 - 340
Fl	0.14	0.13 - 0.17	0.13	0.11 - 0.15	0.14	0.11 - 0.18	0.15	0.09 - 0.18	0.26	0.22 - 0.32
HCO_3	281	244 - 328	253	153 - 501	301	180 - 610	337	174 - 589	435	332 - 494
TDS	256	219 - 302	230	153 - 427	274	181 - 534	328	175 - 539	802	569 - 935
Alkalinity	234	201 - 269	215	144 - 411	254	148 - 501	287	143 - 483	390	282 - 443
pH[3]	8.3	8 - 8.5	8.4	7.8 - 8.8	8.3	7.7 - 8.7	8.4	7.9 - 8.9	8.6	8.5 - 8.9
DIC	58.1	49 - 68	51.9	21 - 107	62.3	37 - 133	70.2	36 - 124	90.5	66 - 100
DOC	3.3	0.9 - 8.1	5.8	3.5 - 8.3	14.4	7.5 - 19	14.8	6.3 - 22	18.3	18 - 19
PC	1.12	L0.01 - 8.54	5.31	L0.01 - 58	1.25	0.18 - 5.54	1.71	L0.01 - 12.79	1.57	0.48 - 2.30
Phenolics	0.003	L0.002 - 0.008	0.004	L0.002 - 0.011	0.007	0.003 - 0.019	0.008	0.003 - 0.018	0.013	0.009 - 0.022
Coliforms-Total[4]	661	24 - 4500	316	0 - 1220	193	6 - 1800	57	6 - 290	43	8 - 100
-Fecal[4]	591	6 - 4500	25	0 - 200	69	0 - 592	44	0 - 284	19	4 - 32
Si	7.4	4.8 - 9.8	5.3	2.4 - 11.3	5.1	L0.5 - 11.7	4.4	0.6 - 11.4	4.9	1.8 - 10.4
TKN	0.345	0.080 - 1.460	0.816	L0.050 - 5.000	0.953	0.580 - 2.000	1.030	0.640 - 1.540	1.315	1.250 - 1.430
NIT	0.049	0.001 - 0.180	0.023	L0.001 - 0.180	0.098	0.003 - 0.730	0.089	L0.001 - 0.520	0.097	L0.001 - 0.380
NH_3	0.032	0.003 - 0.114	0.026	L0.002 - 0.110	0.045	0.004 - 0.220	0.064	0.007 - 0.300	0.027	0.010 - 0.060
TP	0.031	0.014 - 0.064	0.125	L0.006 - 1.300	0.071	0.028 - 0.215	0.106	0.034 - 0.220	0.232	0.092 - 0.350
DP	0.016	0.008 - 0.030	0.013	0.004 - 0.028	0.041	0.014 - 0.090	0.063	0.018 - 0.140	0.160	0.156 - 0.164

[1] JTU
[2] $\mu S \cdot cm^{-1}$
[3] median
[4] # per 100 mL
L = less than

Table 3. [Continued]

	KNEEHILLS		ROSEBUD		MATZHIWIN		ONETREE	
	Mean	Range n=5	Mean	Range n=13	Mean	Range n=10	Mean	Range n=10
DO	10.1	8.2 - 11.5	10.0	7.6 - 12.3	9.1	6.8 - 11.9	9.2	7.5 - 12.1
COD	48.9	38.4 - 79.1	29.0	11.2 - 64.6	21.5	5.7 - 55.6	35.2	17.7 - 82.7
BOD	3.1	1.8 - 4.8	2.9	1.2 - 8.0	2.2	1.3 - 3.7	2.8	1.4 - 5.0
Turbidity[1]	88.0	15.0 - 350.0	61.4	3.0 - 200.0	45.3	8.5 - 90.0	91.0	25.0 - 400.0
Conductivity[2]	1051	645 - 1269	840	404 - 1489	716	377 - 3060	1427	498 - 8300
Na	168	86 - 218	102	27 - 200	72	20 - 450	207	34 - 1600
Ca	36	31 - 46	47	29 - 69	45	26 - 125	64	38 - 220
Mg	20	11 - 26	24	14 - 39	25	14 - 105	51	19 - 290
K	9.4	7.7 - 11.5	4.2	1.5 - 8.0	3.6	1.6 - 14.0	5.2	2.7 - 16.0
Cl	10	6 - 12	10	3 - 24	8	4 - 31	12	5 - 52
SO_4	213	110 - 255	191	54 - 436	218	64 - 1360	619	120 - 4625
Fl	0.25	0.20 - 0.28	0.19	0.14 - 0.25	0.17	0.14 - 0.21	0.20	0.16 - 0.29
HCO_3	390	257 - 478	275	173 - 411	184	117 - 409	202	158 - 399
TDS	656	390 - 800	528	219 - 967	481	201 - 2286	1135	301 - 6999
Alkalinity	334	218 - 410	236	147 - 361	154	112 - 336	166	131 - 328
pH[3]	8.4	8.4 - 8.7	8.5	7.9 - 8.7	8.1	7.7 - 8.7	8.0	7.7 - 8.4
DIC	72.8	53.0 - 96.0	57.5	31.0 - 93.0	38.0	27.0 - 84.0	41.6	30.0 - 80.0
DOC	15.4	13.0 - 22.0	7.3	2.5 - 14.0	4.9	2.3 - 18.0	8.6	4.9 - 29.0
PC	5.78	1.20 - 20.00	4.12	0.23 - 10.19	3.60	2.00 - 6.70	4.27	2.30 - 8.30
Phenolics	0.009	0.005 - 0.014	0.004	L0.002 - 0.008	0.004	L0.002 - 0.016	0.005	0.002 - 0.014
Coliforms-Total[4]	253	0 - 1000	586	2 - 5200	637	32 - 1800	700	110 - 1700
-Fecal[4] 201		0 - 800	450	0 - 5000	166	0 - 430	339	10 - 1500
Si	3.7	2.0 - 7.3	2.3	0.7 - 5.2	3.0	0.8 - 8.7	5.1	2.0 - 7.8
TKN	1.314	0.920 - 2.050	0.838	0.460 - 1.550	0.636	0.360 - 1.700	1.059	0.580 - 2.600
NIT	0.174	L0.001 - 0.690	0.014	L0.001 - 0.103	0.121	L0.001 - 0.430	0.155	L0.001 - 1.150
NH_3	0.033	0.007 - 0.084	0.024	0.005 - 0.100	0.047	0.010 - 0.300	0.039	0.008 - 0.170
TP	0.211	0.026 - 0.750	0.161	0.018 - 0.475	0.151	0.050 - 0.300	0.373	0.118 - 0.810
DP	0.023	0.022 - 0.024	0.024	0.012 - 0.046	0.041	0.016 - 0.086	0.115	0.033 - 0.240

1 JTU
2 $\mu S \cdot cm^{-1}$
3 (median)
4 # per 100 mL
L = less than

total Kjeldahl nitrogen) were also significant (r = 0.78, 0.73, and 0.58, respectively).

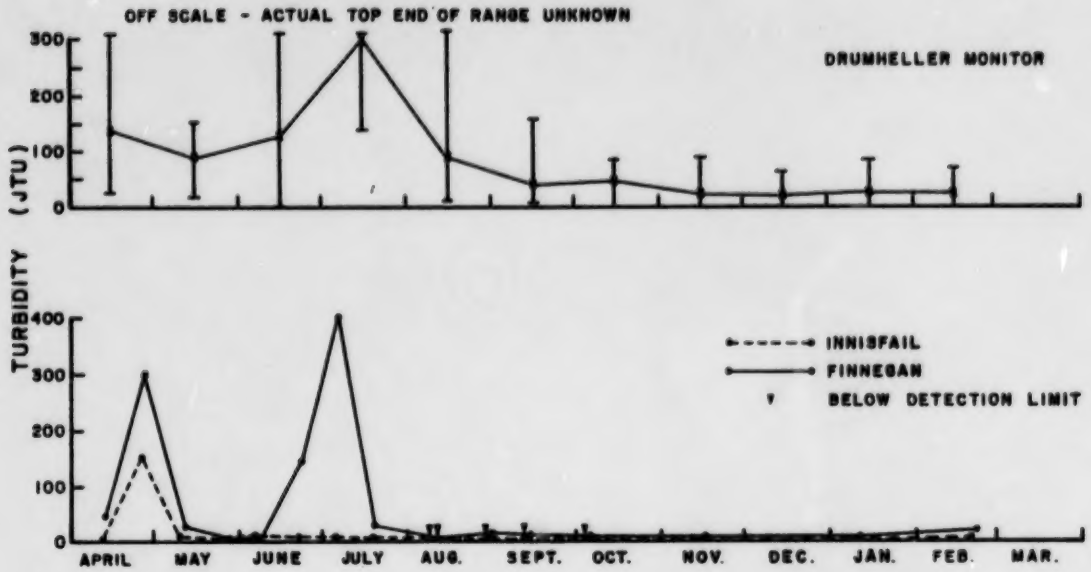
For the mainstem river sites, non-filterable residue and turbidity values decreased from high mean annual values above the Dickson Dam (Site 1) to low mean annual values in the river from below the Dickson Dam (Site 3) to Trochu (Site 11; Figure 9). Turbidity values increased rapidly from Trochu to below Drumheller (Site 16), then increased gradually near Empress (Site 25). Non-filterable residue concentrations increased near Jenner (Site 22), then decreased to Empress. Seasonally, peak turbidity values were measured in April at all sites and in June/July at sites in the lower reaches of the river (Figure 9). The remote monitor at Drumheller measured the highest average turbidity values in July. Fluctuations were smallest in fall and winter (Figure 9).

In the tributary streams, lower turbidities were measured in the streams entering the upper reaches of the Red Deer River than in those entering the lower reaches (Table 3). Average annual values were 4.1 - 23.8 JTU and 45.3 - 91.0 JTU, respectively.

3.2 WATER CHEMISTRY

3.2.1 Conductivity, Major Ions, and Total Dissolved Solids

Conductivity was low at the sites above and below the Dickson Dam (Sites 1 and 3; Figure 10). Average annual values were 362 and 361 $\mu S \cdot cm^{-1}$, respectively. Conductivity increased slowly toward Trochu (Site 11; 379 $\mu S \cdot cm^{-1}$), then more rapidly to Empress (Site 25; 461 $\mu S \cdot cm^{-1}$). To varying degrees, concentrations of total dissolved solids and many of the major ions follow similar patterns.



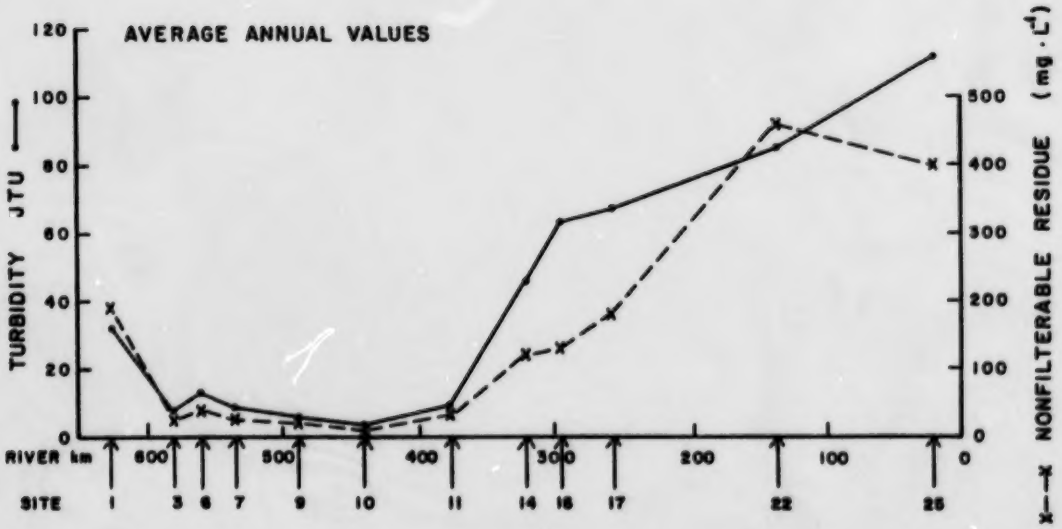


Figure 9. TURBIDITY AND CONCENTRATIONS OF NON-FILTERABLE RESIDUE IN THE RED DEER RIVER.

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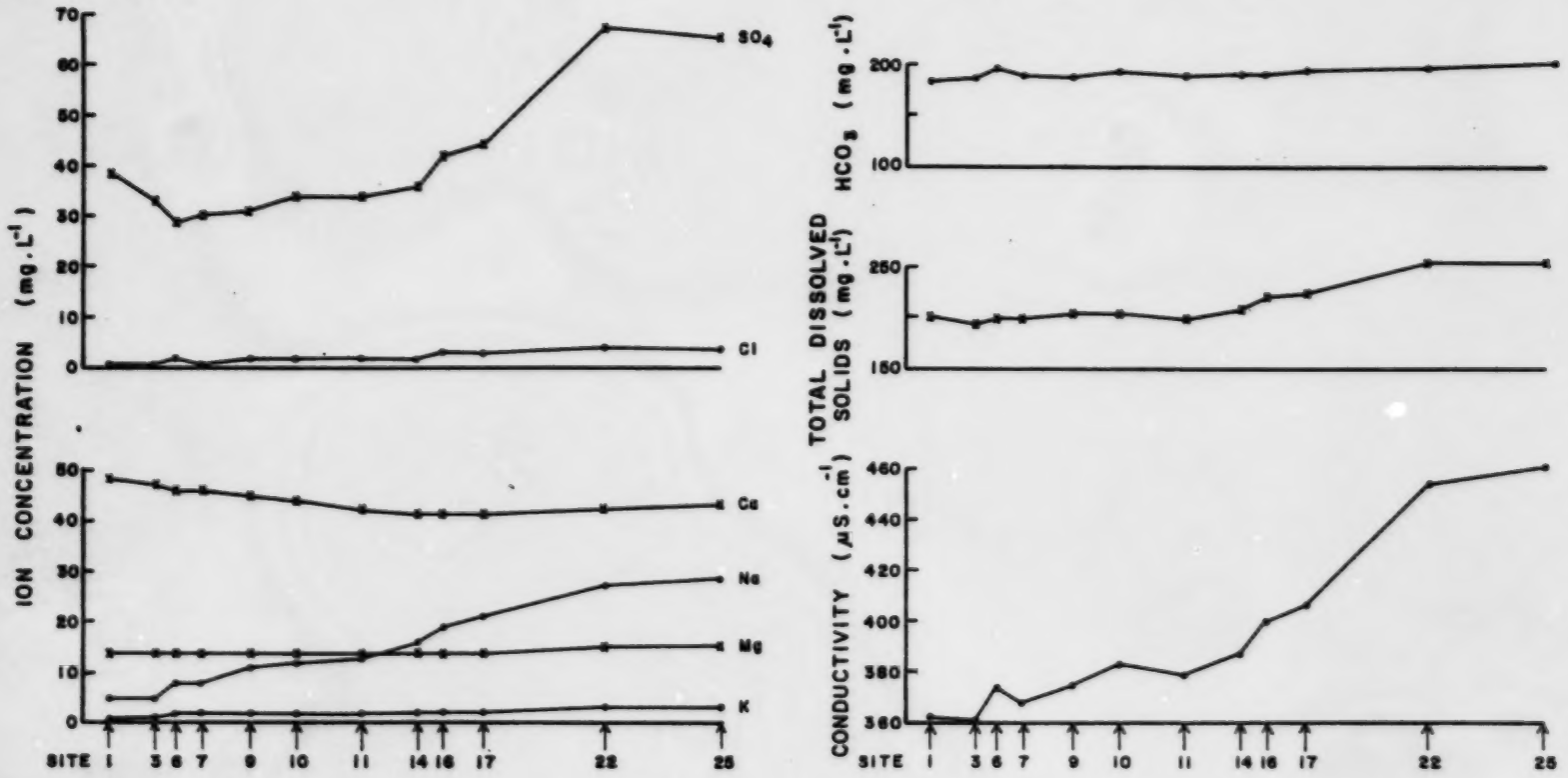

Figure 10. AVERAGE ANNUAL CONDUCTANCE AND CONCENTRATION OF MAJOR IONS AND TDS ALONG THE RED DEER RIVER.

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Average annual values for concentrations of total dissolved solids ranged from 195 to 258 $mg \cdot L^{-1}$; and for sodium, from 4.8 to 28.0 $mg \cdot L^{-1}$; potassium, from 1.0 to 3.0 $mg \cdot L^{-1}$; magnesium, from 13.6 to 15.4 $mg \cdot L^{-1}$; chloride, from less than 1.0 to 4.0 $mg \cdot L^{-1}$; sulphate, from 29.2 to 67.2 $mg \cdot L^{-1}$; and bicarbonate, from 185 to 203 $mg \cdot L^{-1}$ (Figure 10). The one exception was calcium, which on average decreased in concentration from above the Dickson Dam (Site 1; 47.6 $mg \cdot L^{-1}$) to Finnegan (Site 17; 40.7 $mg \cdot L^{-1}$) before increasing near Empress (Site 25; 42.9 $mg \cdot L^{-1}$).

Seasonally, conductivity values were variable. In general higher values from April to early July were followed by low values until September and increasing values through to February (Figure 11a). Calcium, bicarbonate, and in relative terms, magnesium, showed the winter increase more strongly (Figures 11a, b). The higher spring/lower summer trends were more obvious for sodium and sulphate in the lower reaches of the Red Deer River.

Seasonal data from the monitor in Drumheller showed the lowest average conductivity values in August and the highest average values in July and December (Figure 11b). The variability in conductivity values was highest in April and lowest in February.

Average annual conductivity and concentrations of total dissolved solids in the tributaries ranged from 427 $\mu S \cdot cm^{-1}$ and 230 $mg \cdot L^{-1}$ in the Little Red Deer River to 1427 $\mu S \cdot cm^{-1}$ and 1135 $mg \cdot L^{-1}$ in Onetree Creek (Table 3). In general, conductivity was lower in tributaries of the upper reaches of the Red Deer River than in those of the lower reaches. Onetree Creek had the highest average

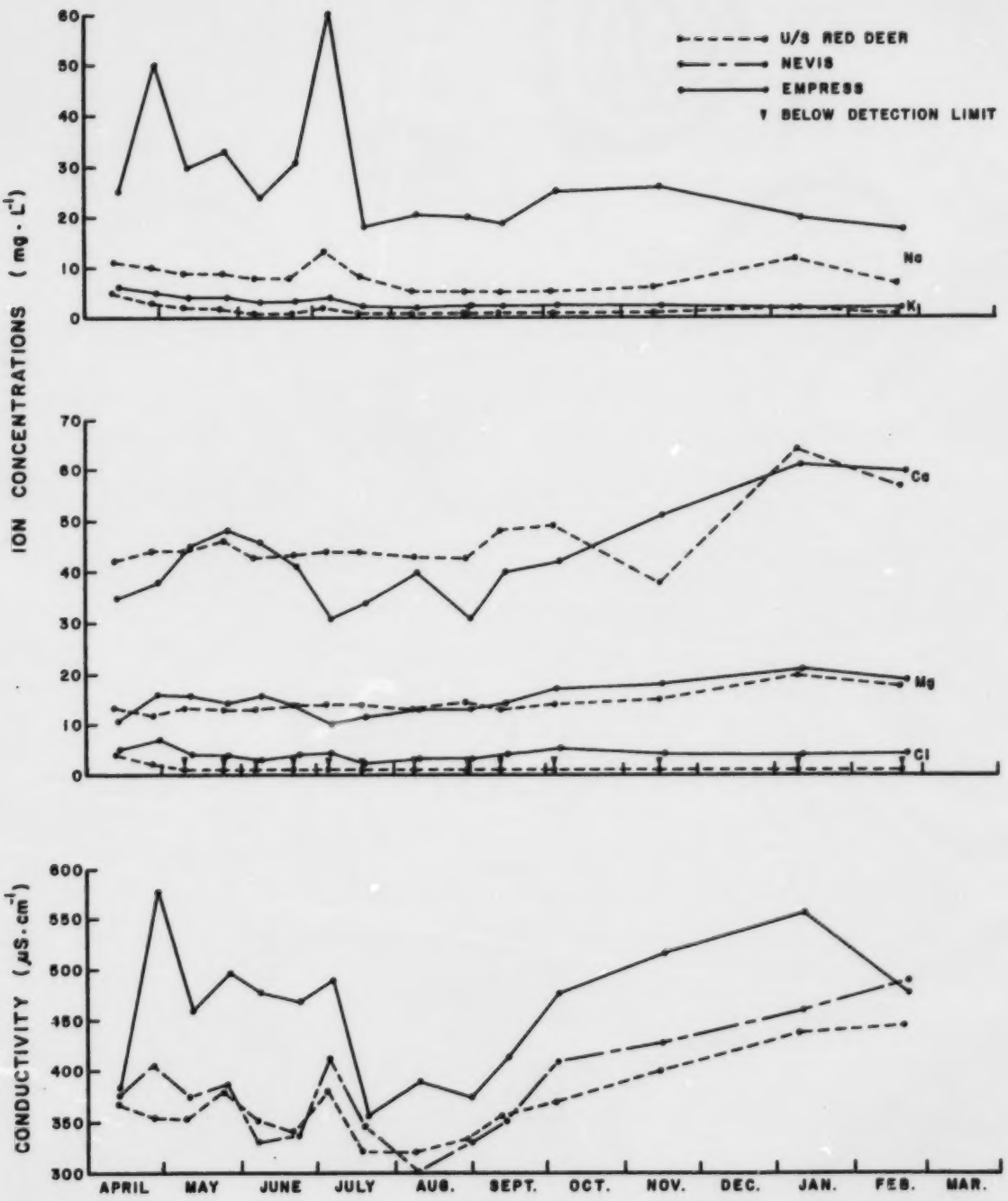

Figure 11a. CONDUCTIVITY AND CONCENTRATIONS OF MAJOR IONS AT REPRESENTATIVE SITES ON THE RED DEER RIVER.

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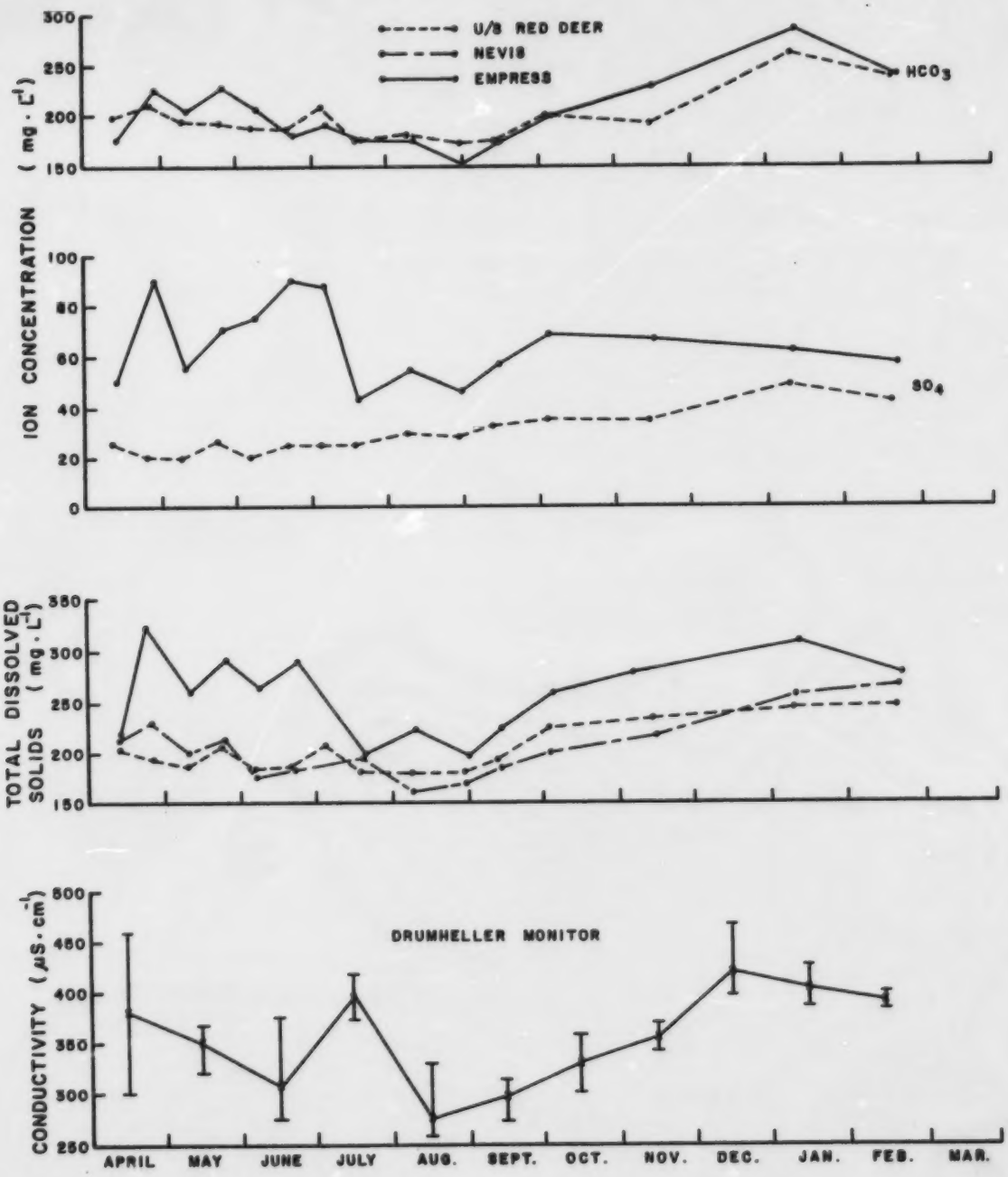

Figure 11b. CONDUCTIVITY AND CONCENTRATIONS OF MAJOR IONS AT REPRESENTATIVE SITES ON THE RED DEER RIVER.

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annual concentration of the major ions sodium, calcium, magnesium, chloride, and sulphate. Concentrations of potassium and fluoride were highest in Threehills Creek. The lowest concentrations of sodium, potassium, and chloride were measured in the Raven River; of magnesium, sulphate, and fluoride, in Little Red Deer River and of calcium in Kneehills Creek.

3.2.2 Alkalinity and pH

Alkalinity of the river water was moderate, averaging 155 $mg \cdot L^{-1}$ above and below the Dickson Dam (Sites 1 and 3), but increasing to average values ranging from 163 to 168 $mg \cdot L^{-1}$ at all downstream sites until Empress (Site 25; 173 $mg \cdot L^{-1}$; Figure 12). Seasonal trends were similar to those for conductivity, values generally decreasing from April to August before increasing to highs in February (Figure 13).

Average annual alkalinity in the tributary streams ranged from 154 $mg \cdot L^{-1}$ $CaCO_3$ in Matzhiwin Creek to 390 $mg \cdot L^{-1}$ $CaCO_3$ in Threehills Creek (Table 3). The upper reach tributaries and Rosebud River had intermediate values. This may be due to the fact that the upper reach tributaries and the Rosebud River were sampled throughout most of the year. In contrast, Kneehills and Threehills creek averages represent spring only, and Matzhiwin and Onetree creeks were sampled less frequently in spring and never in winter.

Median annual pH values in the Red Deer River ranged from 8.3 to 8.5 with a maximum pH of 8.9 measured downstream of Red Deer (Site 9; Figure 12). Seasonally, pH was slightly higher in September and

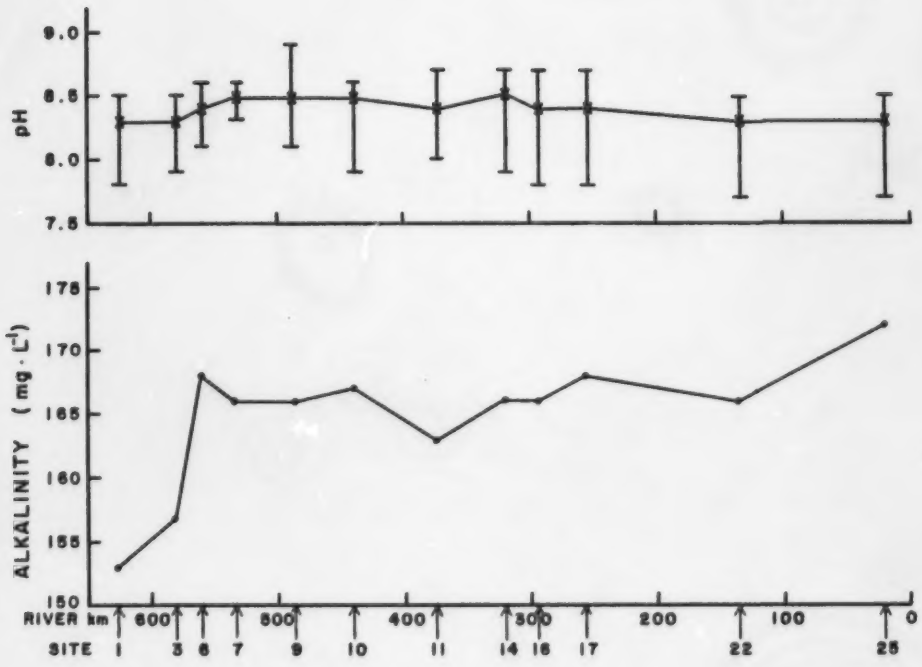

Figure 12. AVERAGE ANNUAL CONCENTRATIONS OF ALKALINITY AND MEDIAN pH AT SITES ALONG THE RED DEER RIVER.

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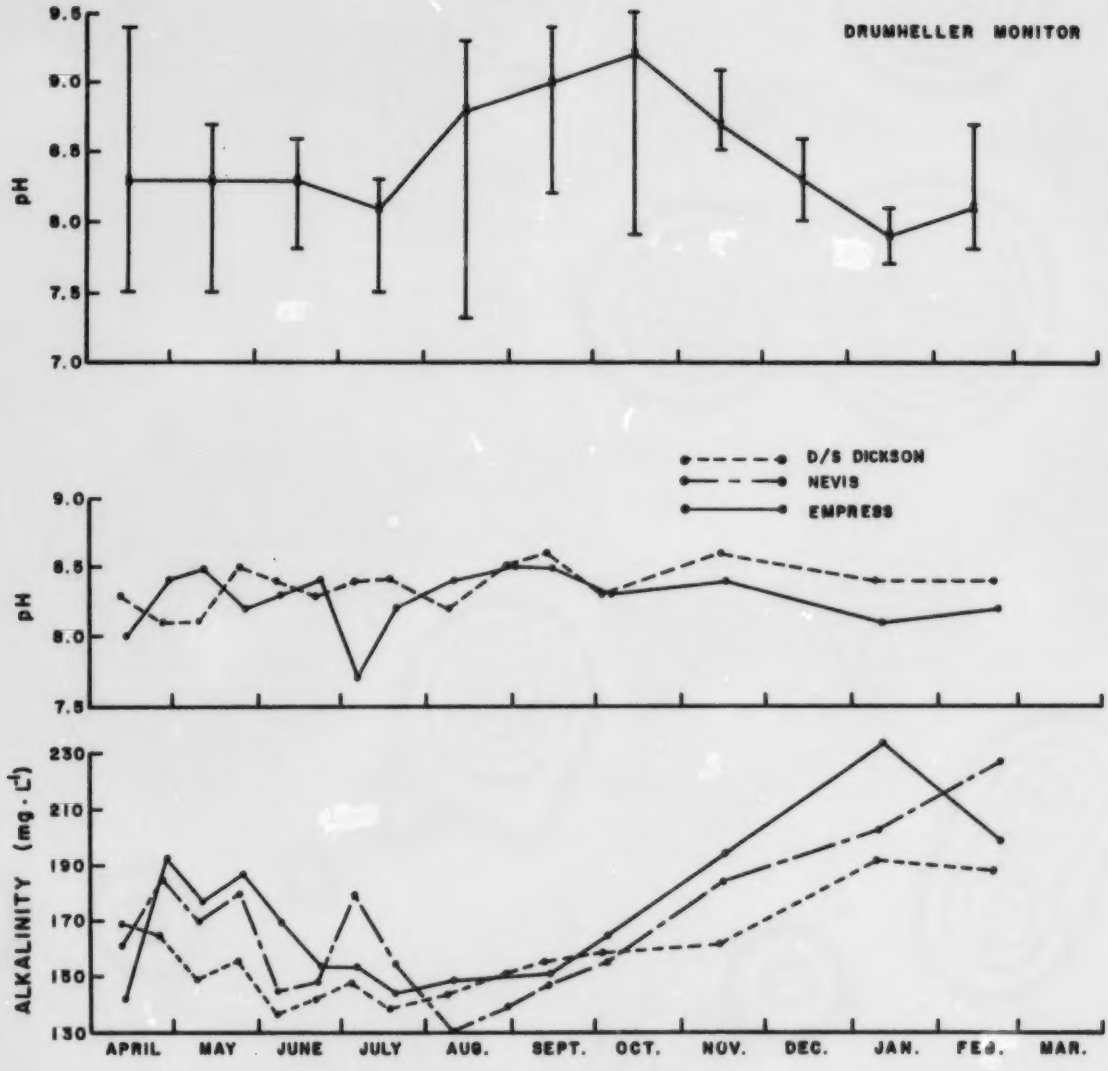

Figure 13. CONCENTRATIONS OF ALKALINITY AND pH AT REPRESENTATIVE SITES ON THE RED DEER RIVER.

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November (Figure 13). Average monthly values from the remote monitor at Drumheller indicate the highest average pH's in October and the lowest in February. The range in pH values was widest in April (7.5 to 9.4) and August (7.3 to 9.3) and narrowest in February (7.7 to 8.1).

In the tributary streams, the median pH values ranged from 8.0 in Onetree Creek to 8.6 in Threehills Creek (Table 3).

3.2.3 Carbon

Average annual concentrations of dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) were consistent along most of the length of the river (4 - 6 $mg \cdot L^{-1}$ and 40 - 42 $mg \cdot L^{-1}$, respectively). However, slightly lower concentrations were measured at the two upstream sites (2 - 3 $mg \cdot L^{-1}$ and 37 - 38 $mg \cdot L^{-1}$, respectively; Figure 14). Average concentrations of particulate carbon (PC) decreased sharply from above (Site 1) to below (Site 3) the Dickson Dam. Concentrations remained low until Trochu (Site 11), then increased to Empress (Site 25).

Seasonally, concentrations of DOC in the river decreased from April to June, increased slightly in July, and decreased again to lows in winter (Figure 14). Dissolved inorganic carbon concentrations increased through April, decreased from late April to August, and increased to highs in January.

Average annual concentrations of DIC and DOC ranged from 38.0 $mg \cdot L^{-1}$ in Matzhiwin Creek and 3.3 $mg \cdot L^{-1}$ in the Raven River to 90.5 $mg \cdot L^{-1}$ and 18.3 $mg \cdot L^{-1}$, respectively, in Threehills Creek (Table 3). Average concentrations of particulate carbon ranged from 1.12 $mg \cdot L^{-1}$ in

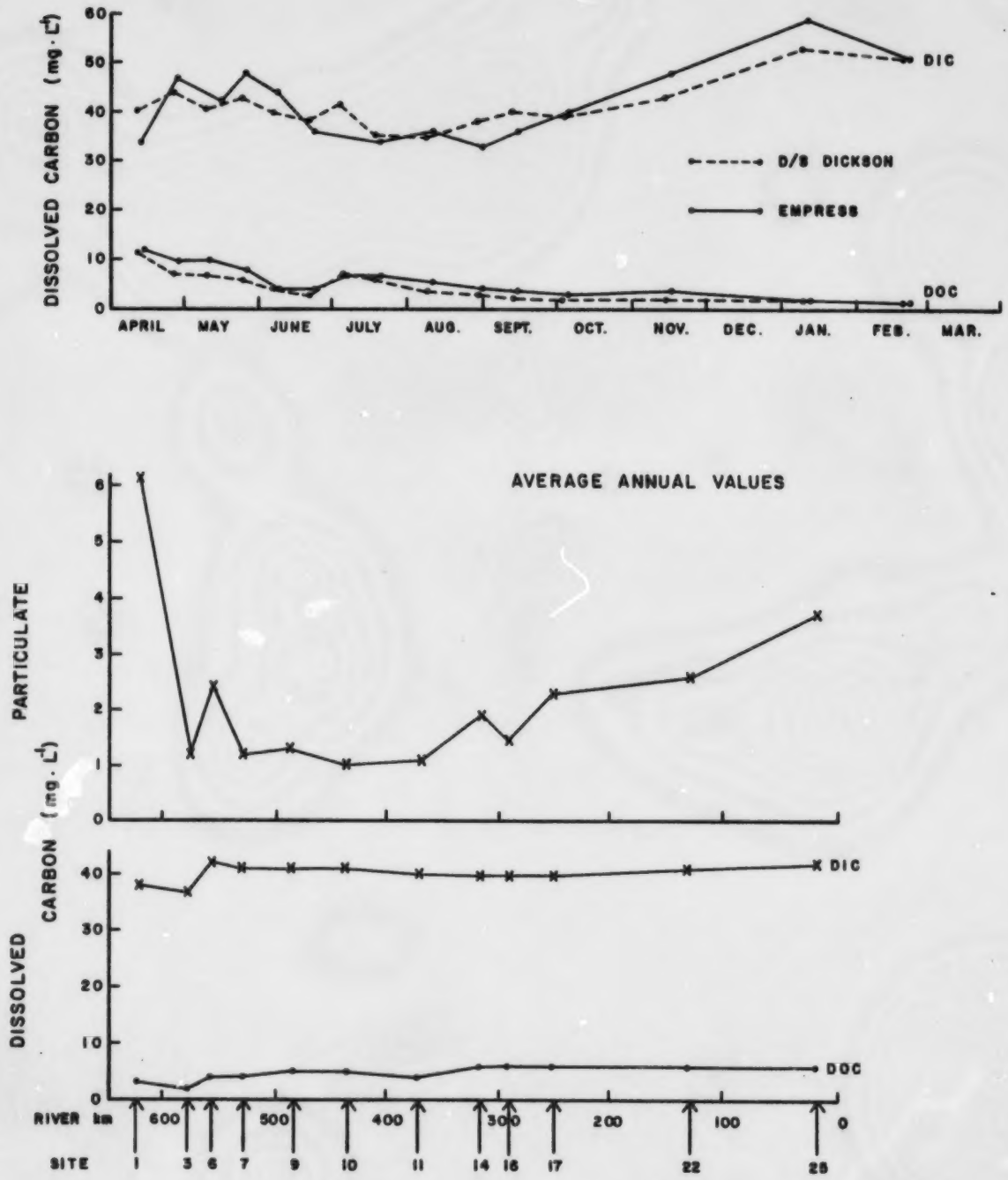

Figure 14. CONCENTRATIONS OF CARBON FORMS IN THE RED DEER RIVER.

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the Raven River to 5.78 mg•L^{-1} in Kneehills Creek.

3.2.4 Phenolics

Average annual concentrations of phenolics ranged from 0.003 to 0.004 mg•L^{-1} with maximum values of 0.012 - 0.014 mg•L^{-1} at all sites except below the Dickson Dam (Site 3) and above the City of Red Deer (Site 7; Figure 15). The higher concentrations were often measured in April or early July.

In the tributary streams, average concentrations of phenolics ranged from 0.003 mg•L^{-1} in the Raven River to 0.013 mg•L^{-1} in Threehills Creek (Table 3).

3.2.5 Silica

Average annual concentrations of silica decreased from above the Dickson Dam (Site 1; 5.0 mg•L^{-1}) to Nevis (Site 10; 2.7 mg•L^{-1}) the most rapid decrease occurring from above (Site 7) to below (Site 9) the City of Red Deer (Figure 15). Concentrations remained fairly constant before increasing at Jenner (Site 22; 3.3 mg•L^{-1}) and Empress (Site 25; 3.6 mg•L^{-1}). Seasonally, peak values occurred in April, July, and January, although this pattern was less distinct at those sites above Red Deer (Figure 15).

Concentrations of silica in the tributaries (averaging 2.3 - 7.4 mg•L^{-1}) were generally higher in the upper reaches of the Red Deer River than in the lower reaches (Table 3). The exception was Onetree Creek, with an average annual concentration of 5.1 mg•L^{-1}.

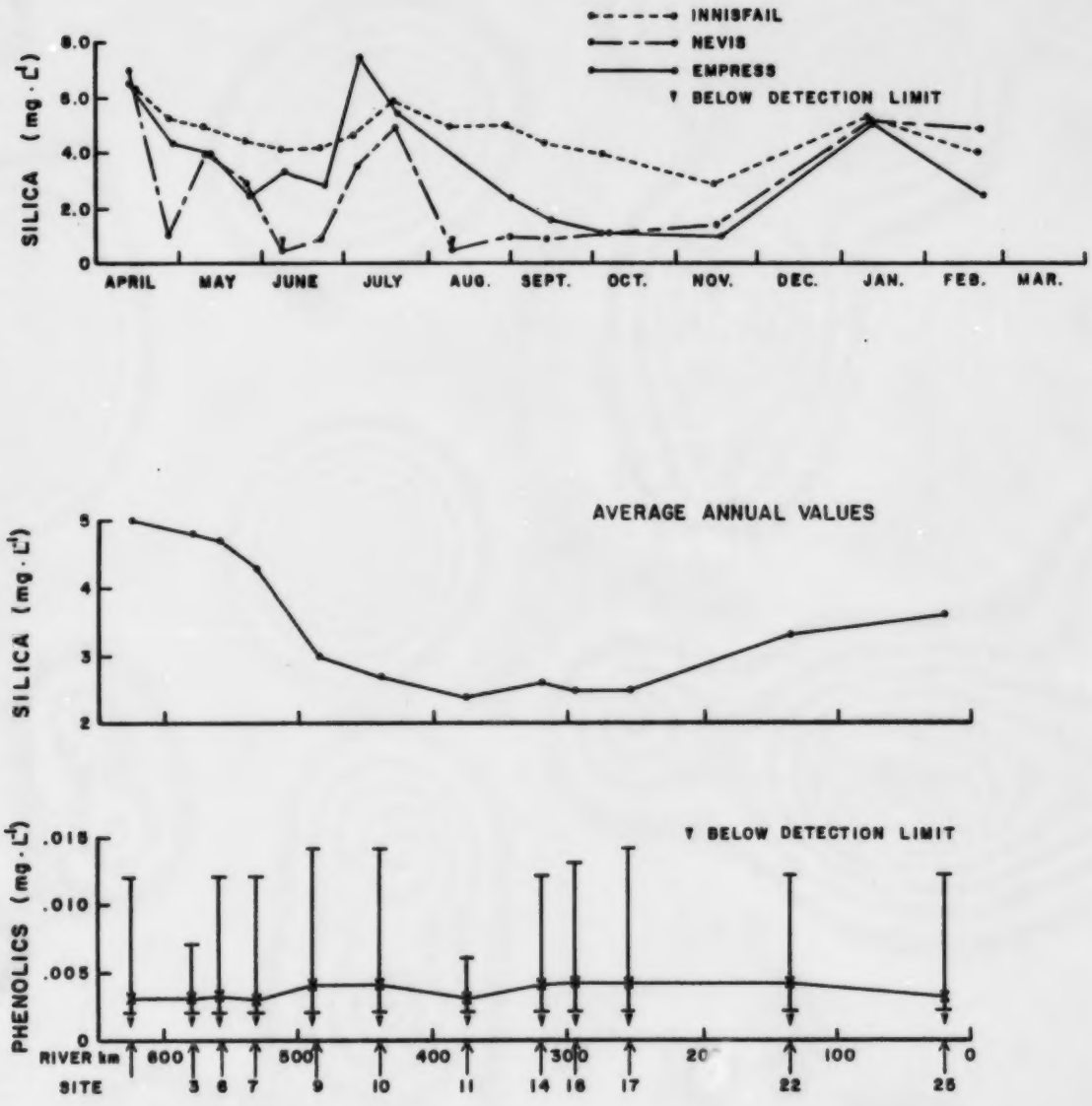

Figure 15. CONCENTRATIONS OF PHENOLICS AND SILICA IN THE RED DEER RIVER.

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Variability in sampling frequency of the different tributaries affected this result to some extent.

3.2.6 Nitrogen

Average annual concentrations of nitrogen increased in a downstream direction; however, the pattern of each form varied (Figure 16). Total Kjeldahl nitrogen (TKN) concentrations decreased from 0.55 $mg \cdot L^{-1}$ above (Site 1) to 0.20 $mg \cdot L^{-1}$ below (Site 3) the Dickson Dam. Values fluctuated from 0.30 to 0.45 $mg \cdot L^{-1}$ until the river reached Trochu (Site 11), then concentrations increased rapidly to 0.77 $mg \cdot L^{-1}$ at Jenner (Site 22). Nitrate plus nitrite (NIT) concentrations showed a similar pattern and ranged from 0.042 to 0.142 $mg \cdot L^{-1}$. Values below Red Deer (Site 9) and at Nevis (Site 10) were distinctly higher than those upstream and downstream and nitrate/nitrite concentrations increased to Empress (Site 25). Ammonia concentrations were low (0.017 - 0.021 $mg \cdot L^{-1}$) at all sites above Red Deer, but increased reaching the highest values below Red Deer (0.060 $mg \cdot L^{-1}$). Concentrations decreased to Trochu (Site 11), then increased again near Jenner (Site 22).

Seasonally, nitrogen forms showed peak values in April and July (Figure 17). Otherwise, nitrogen concentrations were relatively low. The exceptions were nitrate/nitrite and ammonia, both of which also had peak values in January. Total Kjeldahl nitrogen was significantly correlated to both dissolved Kjeldahl nitrogen ($r = 0.66$) and total phosphorus ($r = 0.77$) when all the data from the river basin were combined. Dissolved phosphorus and dissolved Kjeldahl nitrogen were also

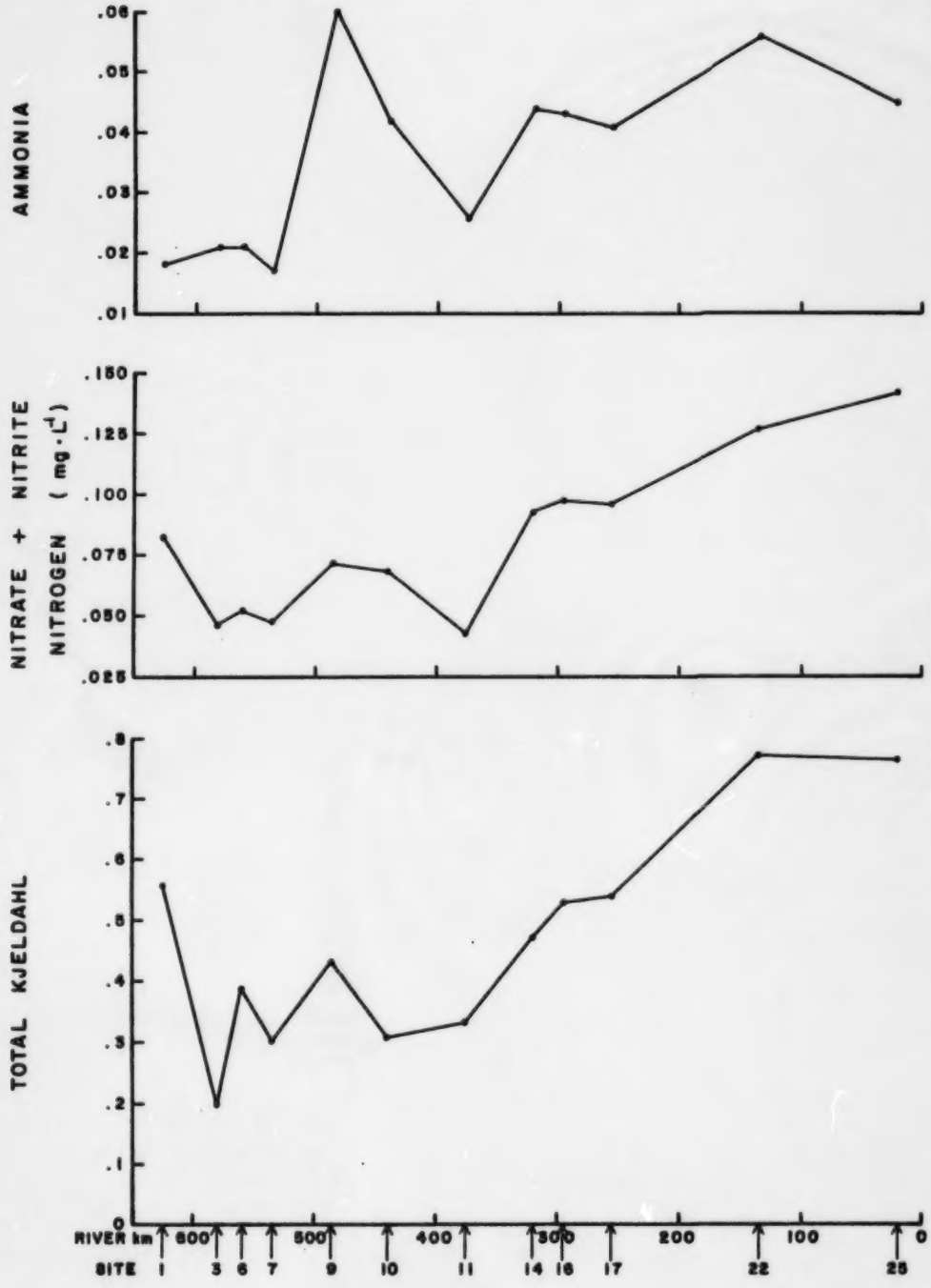

Figure 16. AVERAGE ANNUAL CONCENTRATIONS OF NITROGEN FORMS AT SITES ALONG THE RED DEER RIVER

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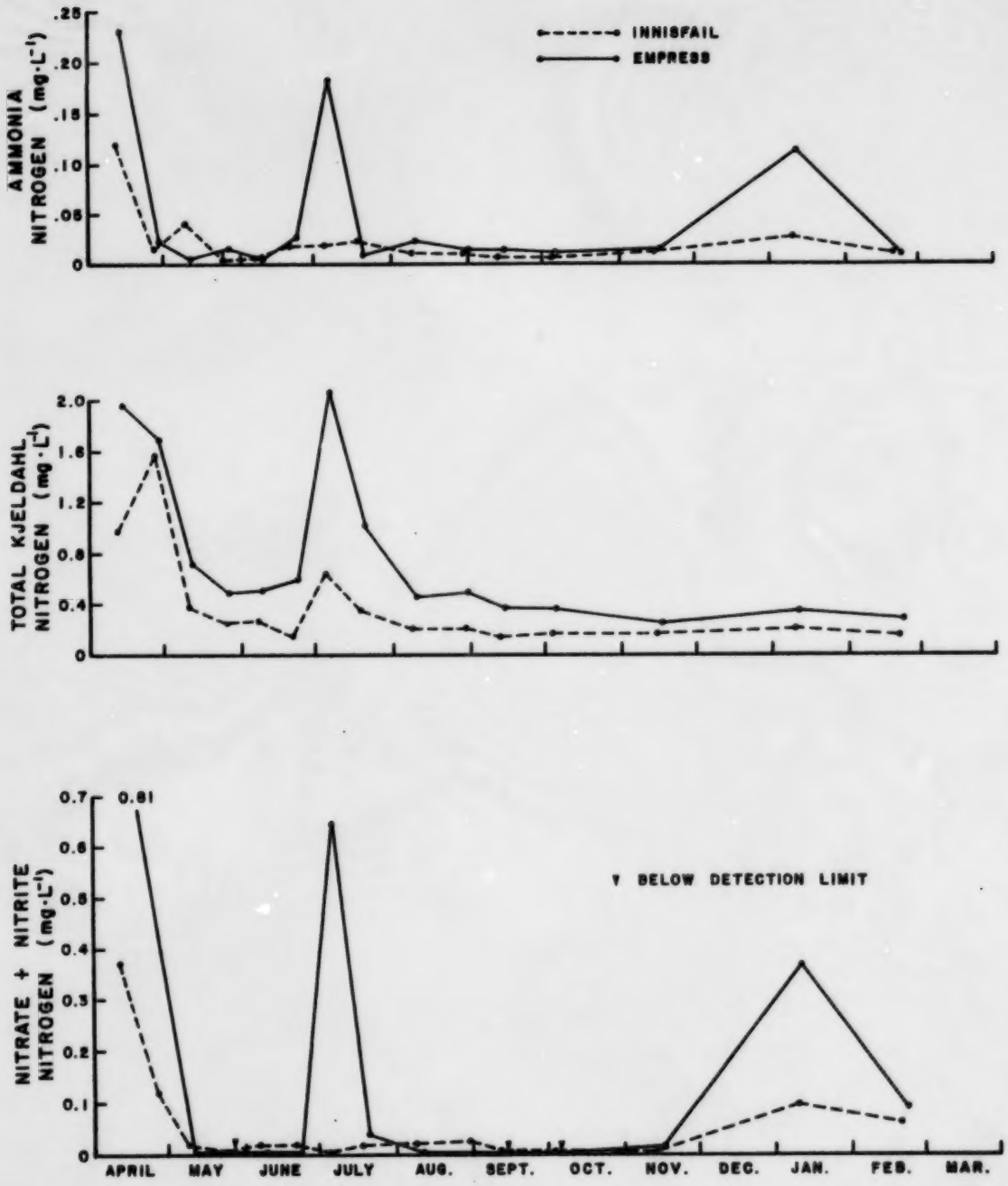

Figure 17. CONCENTRATIONS OF NITROGEN FORMS AT REPRESENTATIVE SITES ON THE RED DEER RIVER

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correlated ($r = 0.61$).

Average annual concentrations of nitrogen forms in the tributaries ranged from 0.345 to 1.315 $mg \cdot L^{-1}$ for total Kjeldahl nitrogen, from 0.014 to 0.174 $mg \cdot L^{-1}$ for nitrate/nitrite, and from 0.024 to 0.064 $mg \cdot L^{-1}$ for ammonia (Table 3).

3.2.7 Phosphorus

Average annual concentrations of dissolved phosphorus (DP) were much lower than concentrations of total phosphorus (TP). Average values ranged from 0.010 to 0.034 $mg \cdot L^{-1}$ for dissolved phosphorus and from 0.027 to 0.209 $mg \cdot L^{-1}$ for total phosphorus. The two phosphorus forms also showed different longitudinal trends (Figure 18). For dissolved phosphorus, distinct concentration peaks were seen at Site 9 below Red Deer (0.034 $mg \cdot L^{-1}$) and Site 14 above Drumheller (0.027 $mg \cdot L^{-1}$). On the other hand, total phosphorus concentrations remained relatively constant from below the Dickson Dam to Drumheller (0.027 - 0.071 $mg \cdot L^{-1}$). Concentrations started increasing at downstream sites, and a peak occurred below Drumheller (Site 16; 0.187 $mg \cdot L^{-1}$).

Seasonally, the trends in the two phosphorus forms were more similar, peak concentrations occurring in April or May and July (Figure 19). From October to February, however, total phosphorus remained relatively constant, whereas dissolved phosphorus values increased.

Average annual concentrations of total phosphorus in the tributaries ranged from 0.031 $mg \cdot L^{-1}$ in the Raven River to 0.373 $mg \cdot L^{-1}$ in Onetree Creek. Dissolved phosphorus concentrations ranged

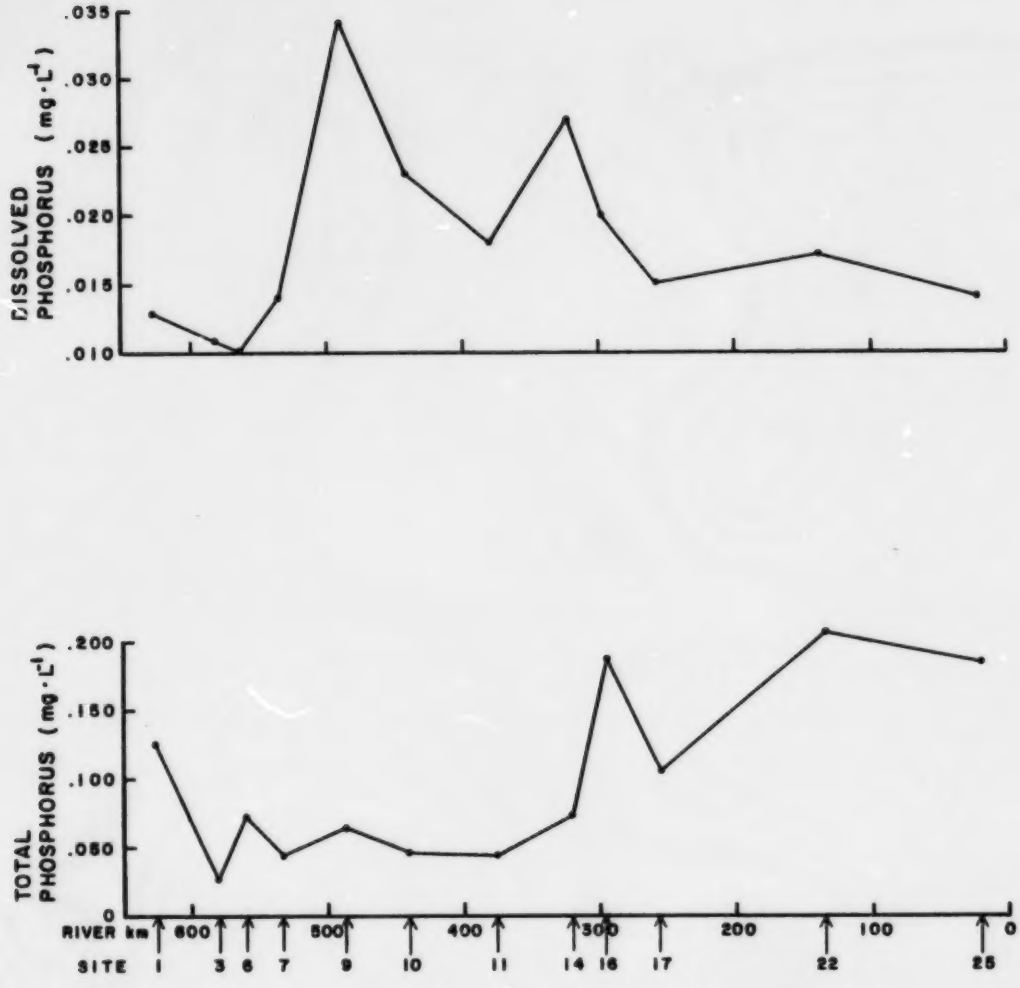

Figure 18. AVERAGE ANNUAL CONCENTRATIONS OF TOTAL AND DISSOLVED PHOSPHORUS AT SITES ALONG THE RED DEER RIVER

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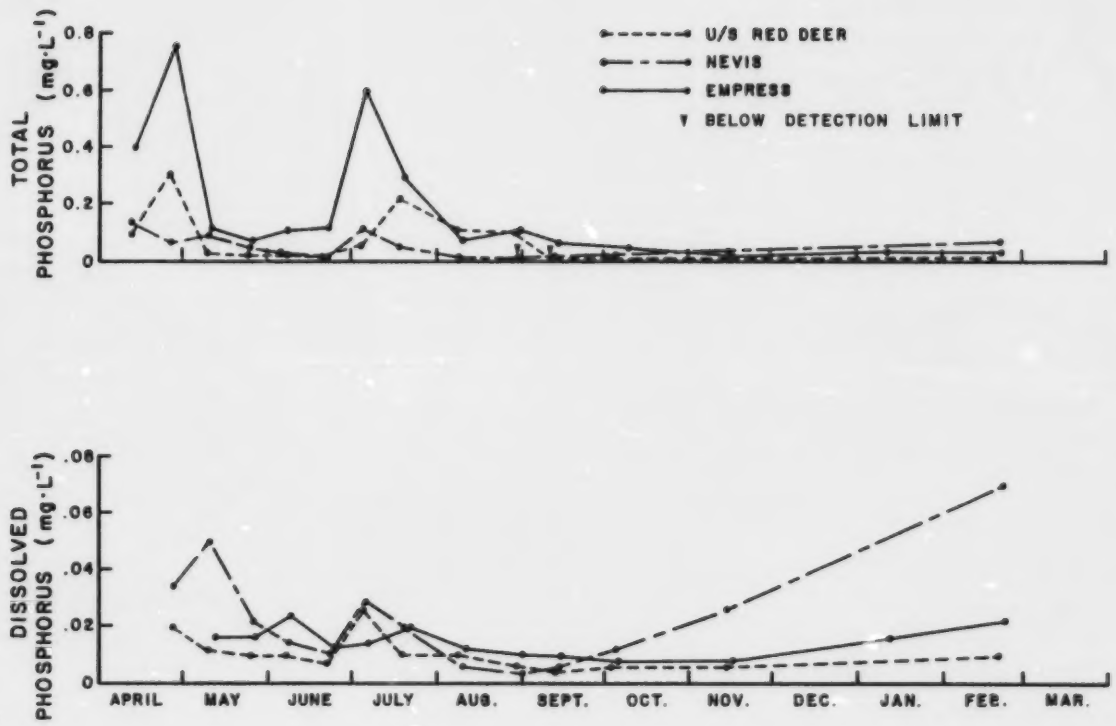

Figure 19. CONCENTRATIONS OF TOTAL AND DISSOLVED PHOSPHORUS AT REPRESENTATIVE SITES ON THE RED DEER RIVER

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from 0.013 $mg \cdot L^{-1}$ in the Little Red Deer River to 0.160 $mg \cdot L^{-1}$ in Threehills Creek (Table 3).

Annual dissolved phosphorus loading decreased from upstream (Site 1) to downstream (Site 3) of the Dickson Dam (from 16 to 11 tonnes; Figure 20). Major increases occurred from Site 3 to below Red Deer (Site 9; 52 tonnes). Loading decreased rapidly to Trochu (Site 11; 35 tonnes), then more slowly to Empress (Site 25; 26 tonnes). The largest loading into the river came from the Red Deer sewage treatment plant (35 tonnes) with substantial contributions from the Medicine and Blindman rivers (10 tonnes each). Smaller phosphorus loadings derived from the remaining tributaries, irrigation return flows, and the Drumheller sewage treatment plant (less than 6 tonnes each).

The inventory for dissolved phosphorus loading in the basin shows that 16% of the loading came from above the first sampling site (above the Dickson Dam), 44% from tributaries of the Red Deer River, and 41% from the Red Deer and Drumheller sewage treatment plants (36% and 5%, respectively).

3.2.8 Metals

Relatively higher concentrations of metals were measured on the late April and early July sampling trips. The results from these trips strongly bias an average concentration, implying that the site above the Dickson Dam had the highest metal concentrations and that the site below the Dickson Dam had the lowest metal concentrations (Table 4). The median concentration eliminates this bias, and a comparison of results from the three sites indicates that metal concentrations at the site

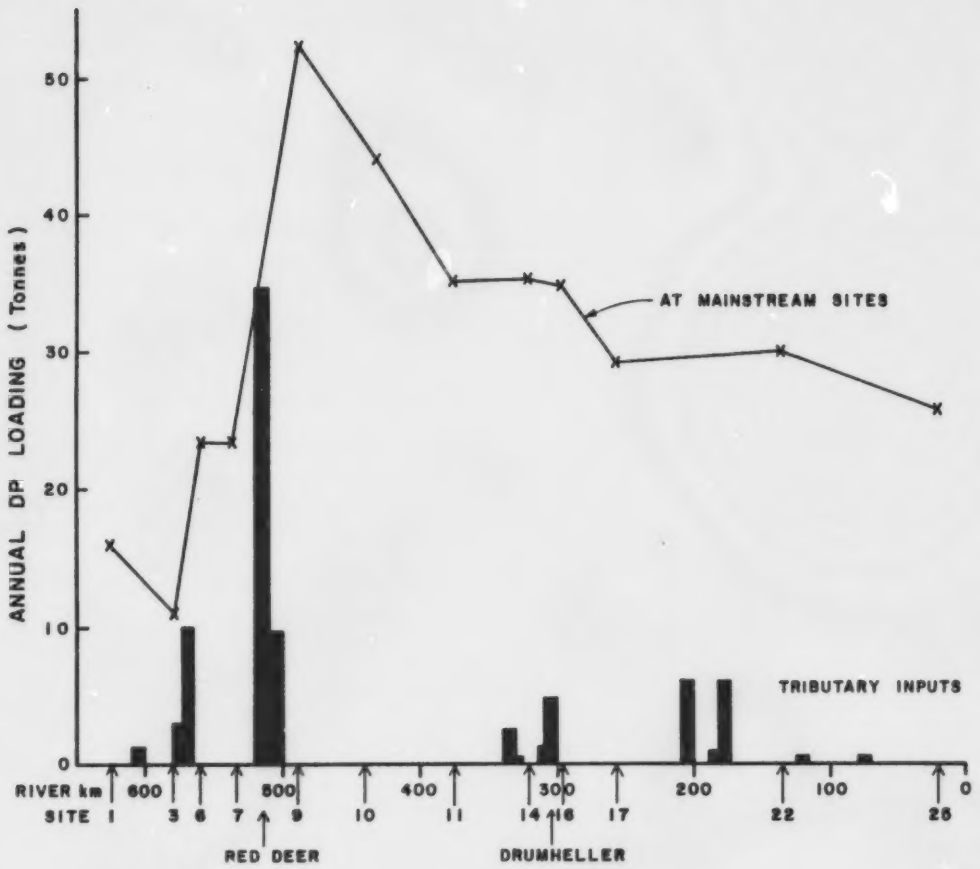

Figure 20. ANNUAL DISSOLVED PHOSPHORUS LOADING INPUTS AND CHANGES AT SITES ALONG THE RED DEER RIVER

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Table 4. Summary of concentrations of metals in water at three sites on the Red Deer River (units are $mg \cdot L^{-1}$).

METAL	ABOVE DICKSON DAM Median	ABOVE DICKSON DAM Range	BELOW DICKSON DAM Median	BELOW DICKSON DAM Range	ABOVE RED DEER Median	ABOVE RED DEER Range
Fe	0.18	L0.02 - 8.68	0.12	0.03 - 0.63	0.12	0.04 - 2.32
Hg	L0.0001		L0.0001		L0.0001	
Co	L0.001	L0.001 - 0.018	L0.001		L0.001	L0.001 - 0.004
Cu	0.002	L0.001 - 0.044	0.002	L0.001 - 0.008	0.002	L0.001 - 0.008
Ni	0.005	L0.001 - 0.049	0.005	L0.001 - 0.010	0.006	L0.001 - 0.153
Cd	L0.001	L0.001 - 0.003	L0.001	L0.001 - 0.003	L0.001	L0.001 - 0.002
Pb	L0.003	L0.003 - 0.012	L0.003	L0.003 - 0.004	L0.003	L0.003 - 0.009
Zn	0.006	L0.001 - 0.135	0.0035	L0.001 - 0.024	0.003	L0.001 - 0.027
Al	0.050	L0.020 - 9.910	0.055	L0.020 - 0.250	0.040	L0.020 - 0.700
Be	L0.001		L0.001		L0.001	
Mn	L0.008	L0.008 - 0.667	0.018	L0.008 - 0.064	0.012	L0.008 - 0.226
Cr	0.004	L0.001 - 0.039	0.003	L0.001 - 0.010	0.003	L0.001 - 0.010
As	0.0005	L0.0002- 0.0190	0.0006	0.0003 -0.0020	0.0006	0.0004 -0.0046
Se	L0.0002		L0.0002		L0.0002	
Va	0.004	L0.002 - 0.059	0.003	L0.002 - 0.007	0.003	L0.002 - 0.015
Mo	L0.001	L0.001 - 0.024	L0.001		L0.001	L0.001 - 0.005

L = less than

above Red Deer were marginally lower. The exception was nickel, which was highest in concentration at the site above Red Deer.

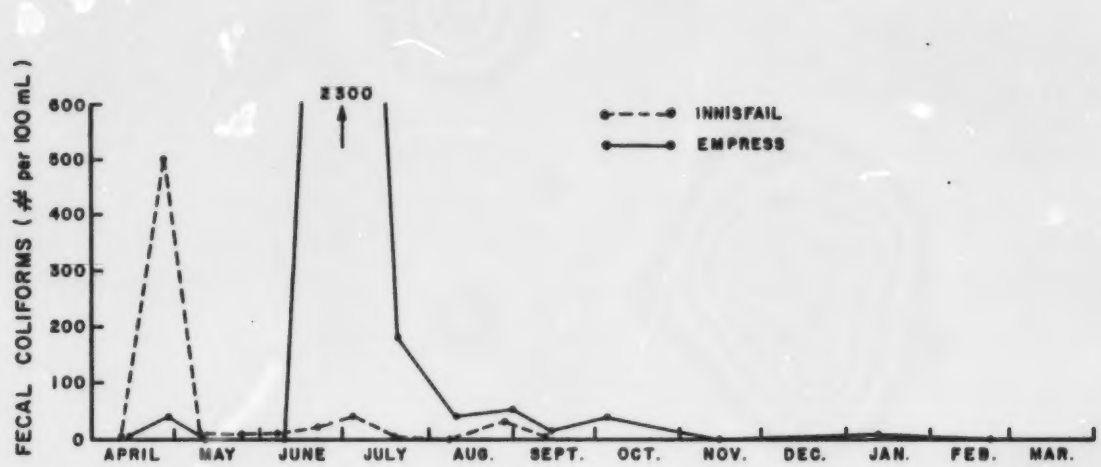
When the two samples of peak concentration were disregarded, metal concentrations seldom exceeded ten times the detection limit. The exceptions were nickel at the site above Red Deer (0.153 $mg \cdot L^{-1}$ on May 9), zinc at the site above the Dickson Dam (0.016 $mg \cdot L^{-1}$ on May 9, 0.016 $mg \cdot L^{-1}$ on June 6, and 0.014 $mg \cdot L^{-1}$ on January 9) and at the site below the Dickson Dam (0.024 $mg \cdot L^{-1}$ on April 11 and 0.012 $mg \cdot L^{-1}$ on June 6), and aluminum at the site above Red Deer (0.385 $mg \cdot L^{-1}$ on April 12). Those metals that never exceeded the detection limit throughout the study were mercury, beryllium, and selenium.

3.3 BIOLOGICAL CONDITIONS

3.3.1 Coliform Bacteria

The pattern of average annual concentrations of coliform bacteria along the length of the river shows several large peaks at Sites 9, 16, and 22 (Figure 21). The first two peaks were below the cities of Red Deer and Drumheller and measured 600 bacteria per 100 mL and 400 per 100 mL for total coliforms and 170 per 100 mL and 130 per 100 mL for fecal coliforms, respectively. The third peak was below the irrigation return flow inputs and the badlands area of the river (810 bacteria per 100 mL and 270 per 100 mL, respectively). Seasonally, peak concentrations occurred in April and June/July at all sites (Figure 21).

Data for the tributary streams showed a wide range of values for coliform bacteria concentrations, from a low average of 19 per 100 mL for



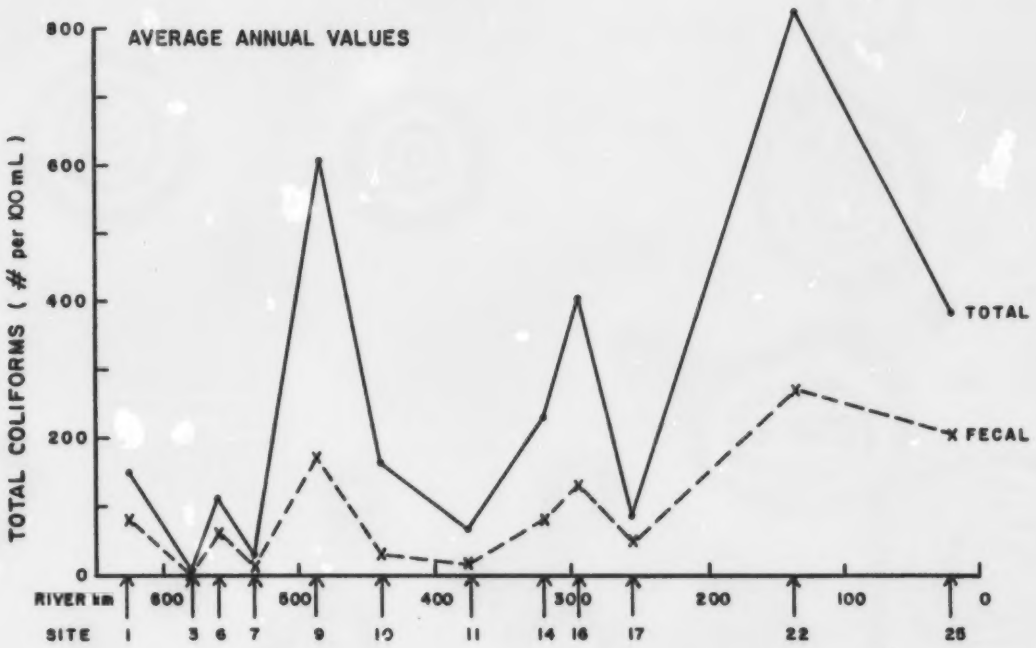


Figure 21. CONCENTRATIONS OF COLIFORM BACTERIA IN THE RED DEER RIVER.

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fecal coliforms and 43 per 100 mL for total coliforms in Threehills Creek to a high average of 591 per 100 mL for fecal coliforms in the Raven River and 700 per 100 mL for total coliforms in Onetree Creek (Table 3).

3.3.2 Algae

In general, phytoplankton populations increased in a downstream direction, ranging from 0.6 to 6.2 $mg \cdot m^{-3}$ chlorophyll *a*. Populations of epilithon (benthic algae) increased rapidly to peak values below Red Deer (Site 9; averaging 104 $mg \cdot m^{-2}$ chlorophyll *a*), then decreased in a downstream direction (Figure 22). Annual average downstream concentrations of epilithon were particularly low below Drumheller (Site 16) and near Jenner (Site 22; 21 and 17 $mg \cdot m^{-2}$ chlorophyll *a*, respectively). This could reflect the effect of increased turbidity on underwater light transmission.

Seasonally, phytoplankton populations were highest in April and moderately high in July (Figure 23). The seasonal pattern for epilithon was quite different at various sites. At Empress, high values in April decreased to lows in June, a second low occurring in October. At Nevis, higher values were measured in April and June, and in September, a very large peak developed. At Innisfail, peak values were in May/June and epilithon populations increased gradually from July to November.

3.3.3 Benthic Invertebrates

The patterns along the length of the river for invertebrate density, wet weight, and number of taxa were similar (Figure 24),

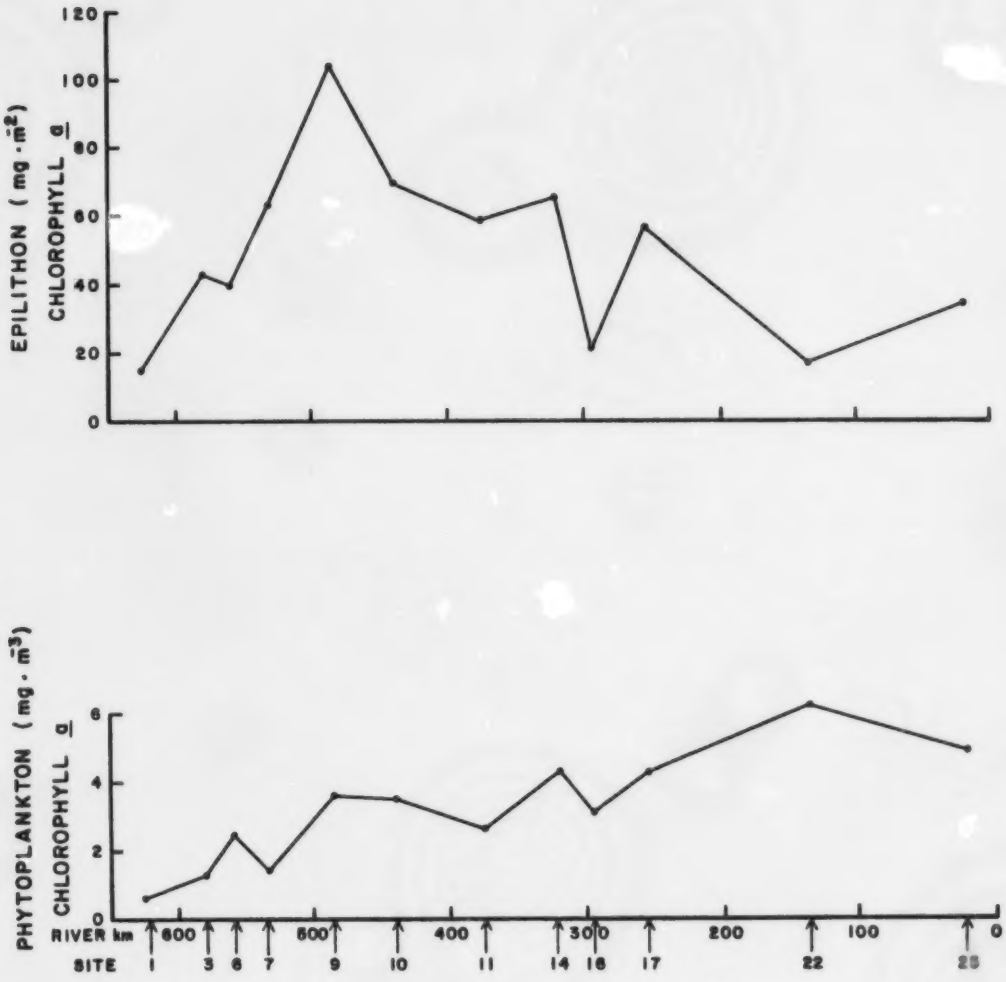

Figure 22. AVERAGE ANNUAL CONCENTRATIONS OF CHLOROPHYLL a AT SITES ALONG THE RED DEER RIVER

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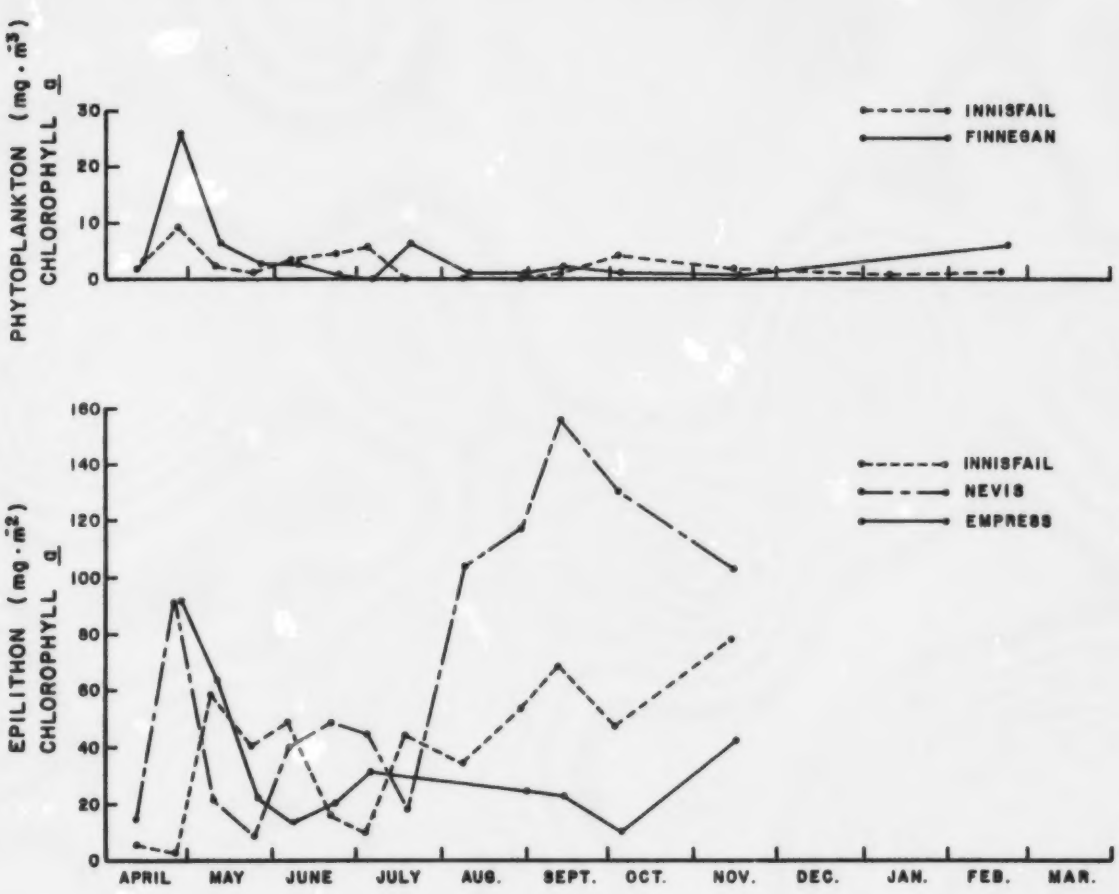

Figure 23. CONCENTRATIONS OF CHLOROPHYLL a AT REPRESENTATIVE SITES ON THE RED DEER RIVER

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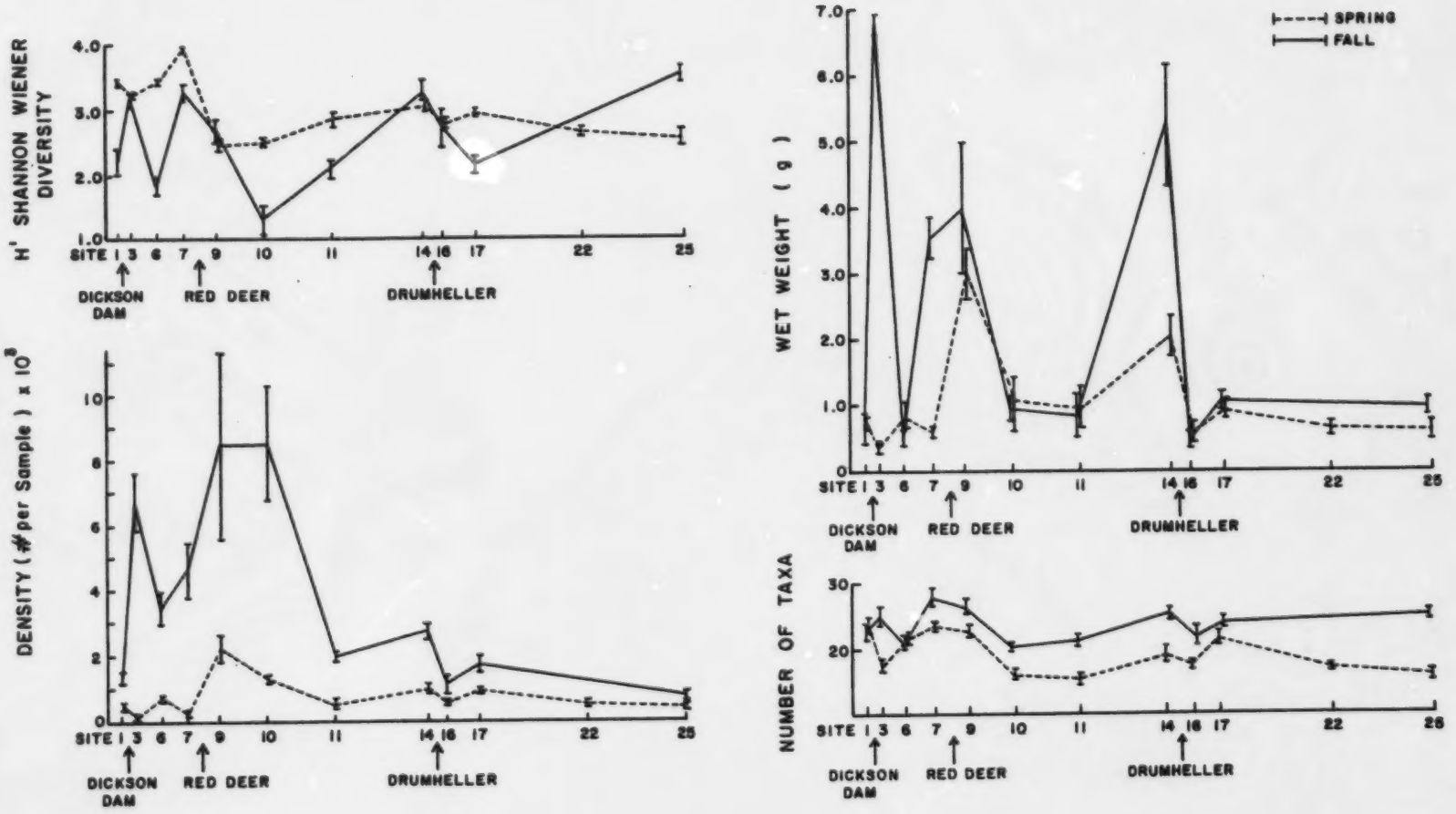
H' SHANNON WIENER DIVERSITY
DENSITY (# per Sample) x 10³
WET WEIGHT (g)
NUMBER OF TAXA
SPRING
FALL
SITE 1 3 6 7 9 10 11 14 16 17 22 25
DICKSON DAM
RED DEER
DRUMHELLER

Figure 24. SUMMARY PARAMETERS FOR BENTHIC INVERTEBRATE DATA FROM THE RED DEER RIVER.

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although fall values were generally higher than were spring values. In both surveys, values increased at Red Deer, and to a lesser degree, above Drumheller. There were, however, several important differences. First, in the upstream reach, there was a marked increase in values at the site below the Dickson Dam in the fall. A slight decrease occurred at the same site in the spring. Second, in the middle reach, the pattern of increased values around Red Deer was slightly different for each parameter. For total number of taxa in both seasons and wet weight in fall, the increase was seen at the sites upstream and downstream of Red Deer. For wet weight in spring, the peak occurred at the site just below Red Deer. For invertebrate density, the peak occurred in both seasons at the sites downstream of Red Deer (Site 10). Third, in the lower reach, the increase above Drumheller was not seen at the site below Drumheller, yet values at Finnegan (Site 17) had increased again.

Some of the differences between spring and fall patterns may be clarified by examining the percentage contribution of major taxa to total numbers (Figure 25). In the spring, there was a general increase in midge (Chironomidae) density and a decrease in mayfly (Ephemeroptera) density in a downstream direction. A shift in community composition occurred below Red Deer, where the percentage contribution of worms (Oligochaeta) increased sharply.

In the fall, the percentage of chironomids in the river was generally much higher than in the spring, except at Site 25 at Empress. However, the omission of a sample from Jenner (Site 22) may have resulted in a distorted image of the longitudinal changes. During autumn, relatively high percentages of trichopterans (Hydropsychidae) were

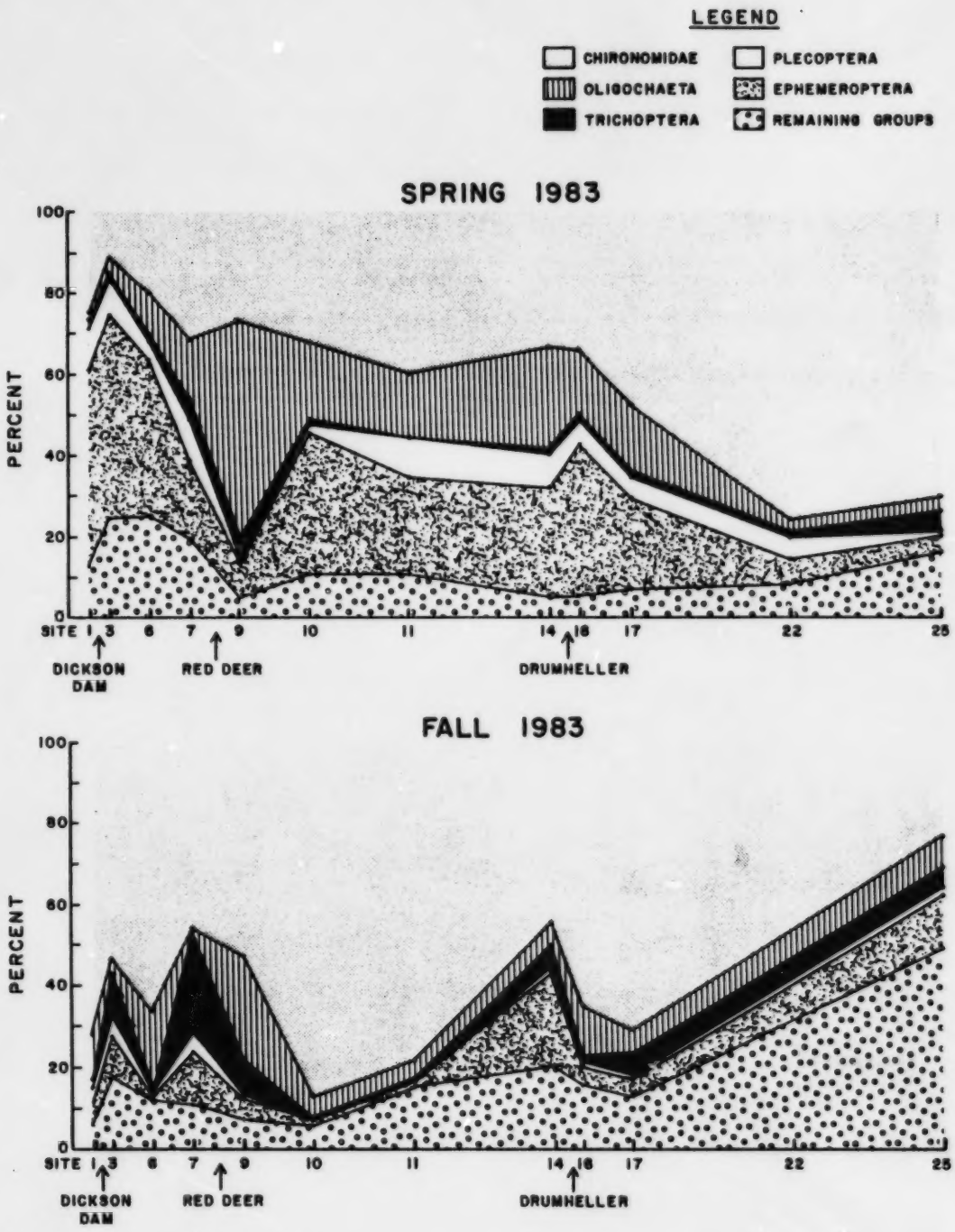

Figure 25. PERCENTAGE CONTRIBUTION OF MAJOR TAXA TO TOTAL NUMBERS OF BENTHIC INVERTEBRATES IN THE RED DEER RIVER.

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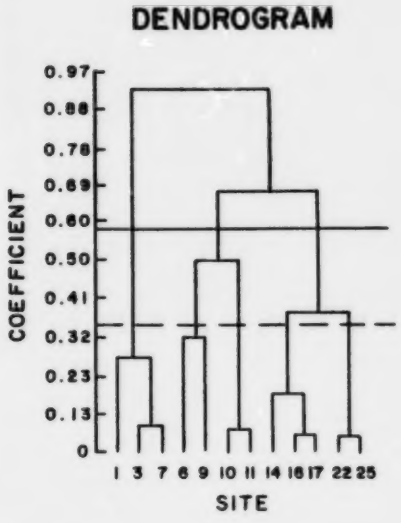
present both below the Dickson Dam and above Red Deer. Oligochaetes were more important at Innisfail (Site 6) and below Red Deer. Ephemeropterans were more important below the Dickson Dam, above Red Deer, and above Drumheller.

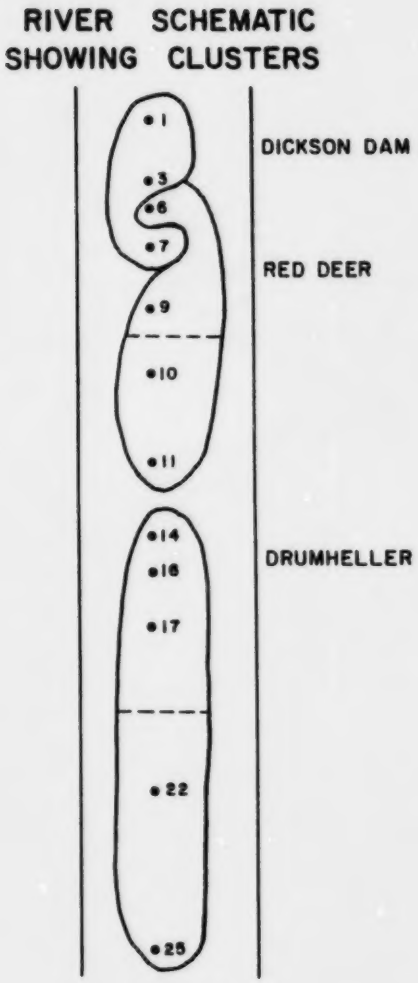
In the upstream reaches of the river (below the Dickson Dam) the differences between benthic invertebrate populations in the spring and fall are the result of differences in the relative contributions of ephemeropterans and chironomids. The percentage of trichopterans is also higher in the fall.

In the middle reaches (around Red Deer), the relatively high percentage of trichopterans above the city in the fall accounts for the higher wet weight values at that time. In the lower reaches, a decrease in wet weight at the site below Drumheller occurred in both seasons.

The Shannon Wiener diversity index (Figure 24) for the spring data was consistently higher at sites above Red Deer and consistently lower at sites downstream of the city. For the fall data, however, the pattern was much different. The index fluctuated between high values below the Dickson Dam, above Red Deer, above Drumheller, and at Empress (Site 25) and lower values above the Dickson Dam, at Innisfail (Site 6), at Nevis (Site 10), and at Finnegan (Site 17).

Cluster analysis on the spring data divided the sites into three major clusters (Figure 26). The first cluster contained sites upstream and downstream of the Dickson Dam and above the City of Red Deer. The second cluster combined the three sites below Red Deer with that at Innisfail (Site 6), and the third cluster contained all the sites from above Drumheller and downstream. The results of principal components





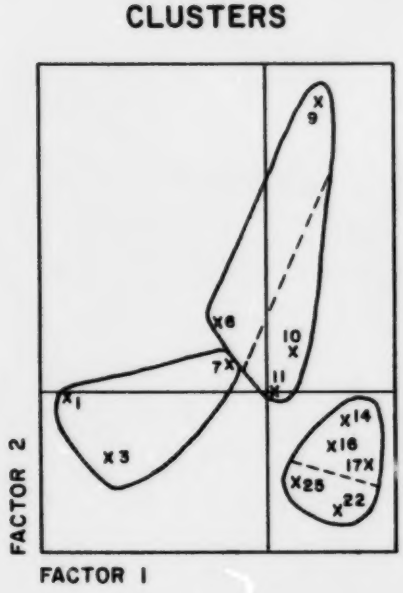


Figure 26. RESULTS OF PRINCIPAL COMPONENTS ANALYSIS OF BENTHIC INVERTEBRATE DATA FROM THE RED DEER RIVER IN SPRING, 1983.

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analysis on these data are summarized in Table 5, vector 1 accounting for 26.5% of the variance, vector 2 for 17.8%, and vector 3 for 12.6%.

The fall data clustered quite differently (Figure 27). One cluster contained only Site 3 below the Dickson Dam. The second cluster combined the sites above and below the City of Red Deer with that above Drumheller. The third cluster contained the remaining seven sites from all reaches of the river, a sub-cluster containing the sites downstream of Drumheller. Principle components analysis accounted for 69% of the variance in the first three vectors (33.4%, 19.2%, and 16.4% for Vectors 1, 2, and 3 respectively; Table 6).

3.4 SEDIMENTS

Sediment chemistry results indicated that chlorinated pesticides, chlorinated herbicides, and PCBs were below detection levels. The results of priority pollutant scans are given in Table 7. Down the length of the river there was a general decrease in molecular sulphur concentrations below Red Deer and from Drumheller to Empress. Branched hydrocarbon concentrations were low above Drumheller (5-10 $\mu g \cdot g^{-1}$), but much higher (70-80 $\mu g \cdot g^{-1}$) at Empress. Various organic compounds were measured at most sites and generally occurred in small amounts (0.01 - 0.1 $\mu g \cdot g^{-1}$). No specific compounds, however, were measured at Empress, and sediments below Drumheller contained small concentrations of eight different organics.

Table 5. Results of principal components analysis of benthic invertebrate data from the Red Deer River in spring, 1983.

	VECTOR 1		VECTOR 2		VECTOR 3
Eigenvalue	10.07		6.75		4.80
Percentage variance	26.49		17.77		12.64
Variance explained by individual taxa					
Orthocladiinae	0.230	Ceraclea	0.344	Acari	0.353
Tanypodiinae	0.210	Heptagenia	0.334	Trichoptera indet.	0.351
Chironomid pupae	0.210	Cheumatopsyche	0.302	Perlidae	0.335
Tanytarsini	0.208	Glossosoma	0.290	Caenis	0.319
Oligochaeta	0.206	Empididae	0.251	Ephemerella	0.307
Tricorythodes	0.199	Oligochaeta	0.238	Chironomini	0.261
Anisoptera	0.177	Nematoda	0.238	Tipulidae	0.252
Chironomini	0.177	Tricorythodes	0.187	Anisoptera	0.217
Perlodidae	0.175	Orthocladiinae	0.159	Empididae	0.198
Brachycentrus	0.170	Ephemerella	0.156	Ameletus	0.171
		Rhagionidae	0.156		
Trichoptera indet.	-0.134				
Ephemerella	-0.159	Ceratopogonidae	-0.157	Taeniopterigidae	-0.162
Chloroperlidae	-0.167	Anisoptera	-0.162		
Ameletus	-0.170	Simuliidae	-0.219		
Taeniopterigidae	-0.173	Chironomid pupae	-0.220		
Corixidae -0.212					
Tipulidae -0.217					
Pteronarcidae	-0.256				
Arctopsyche	-0.277				
Rhithrogena	-0.288				

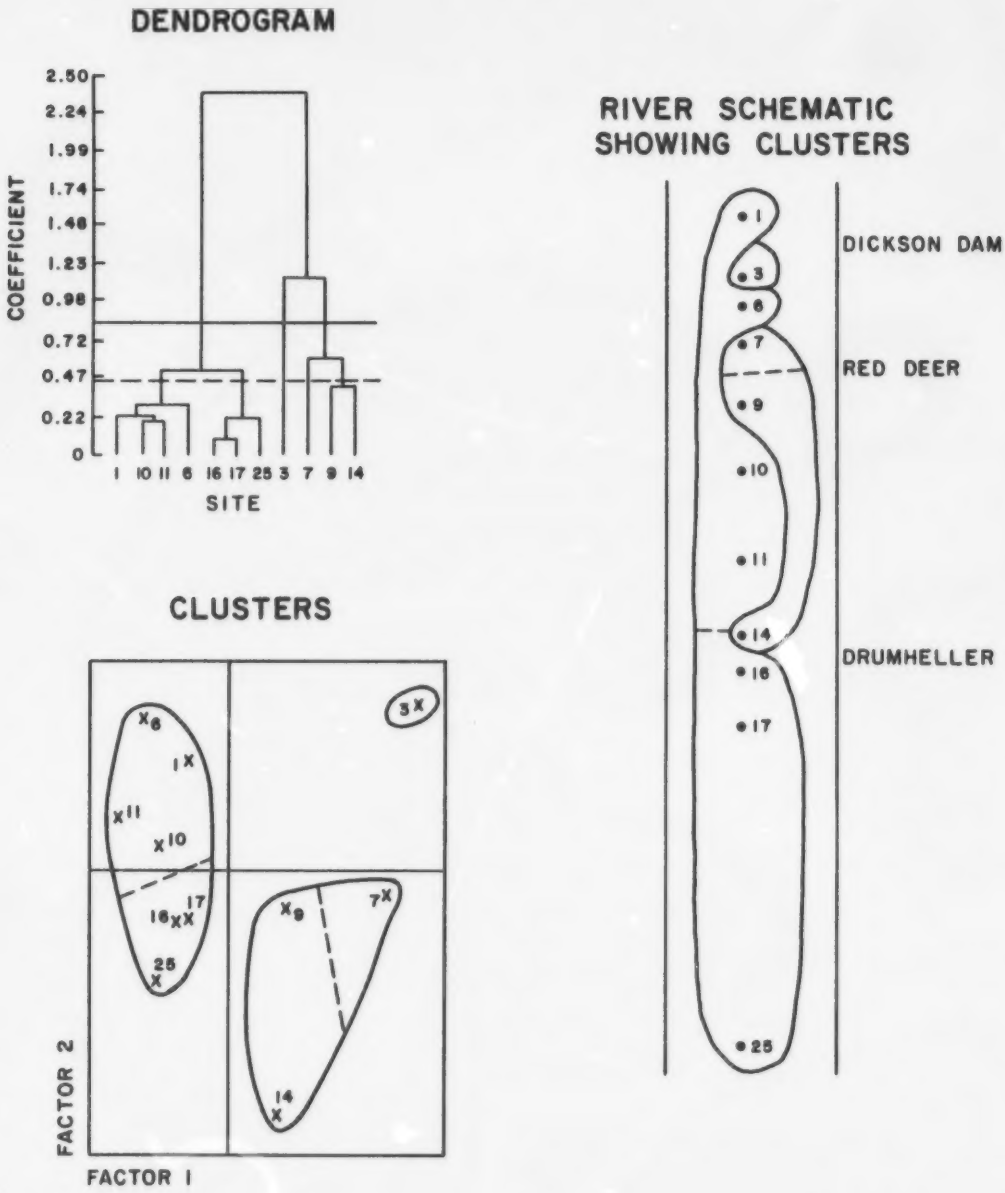

Figure 27. RESULTS OF PRINCIPAL COMPONENTS ANALYSIS OF BENTHIC INVERTEBRATE DATA FROM THE RED DEER RIVER IN FALL, 1983.

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Table 6. Results of principal components analysis of benthic invertebrate data from the Red Deer River in fall, 1983.

	VECTOR 1		VECTOR 2		VECTOR 3
Eigenvalue	15.36		8.89		7.53
Percentage variance	33.39		19.18		16.38
Variance explained by individual taxa					
Perlodidae	0.242	Tanytarsini	0.247	Oligochaeta	0.288
Baetis	0.241	Coelenterata	0.226	Orthocladiinae	0.287
Hydropsyche	0.230	Chironomini	0.182	Nematoda	0.282
Ephemerella	0.226	Chloroperlidae	0.163	Gastropoda	0.282
Glossosoma	0.219	Tipulidae	0.156	Empididae	0.267
Plecoptera indet.	0.218	Traverella	0.156	Tricorythodes	0.236
Ephemeroptera indet.	0.214	Leptophlebia	0.153	Heptageniidae	0.220
Rhithrogena	0.209			Brachycentrus	0.216
Cheumatopsyche	0.209	Ceratopogonidae	-0.156	Elmidae	0.167
Trichoptera indet.	0.206	Tanypodiinae	-0.165	Ameletus	0.150
Pteronarcidae	0.206	Tricorythodes	-0.190		
Perlidae	0.203	Ameletus	-0.192	Perlidae	-0.153
Chloroperlidae	0.196	Brachycentrus	-0.200	Ephemera	-0.176
Simuliidae	0.181	Acari	-0.202	Ceratopogonidae	-0.194
Acari	0.165	Elmidae	-0.204	Caenis	-0.200
Heptagenia	0.161	Heptagenia	-0.217	Siphlonurus	-0.208
Traverella	0.159	Pelecypoda	-0.217	Hexagenia	-0.220
		Hexagenia	-0.222		
Leptophlebia	-0.117	Baetisca	-0.250		
Caenis	-0.133	Anisoptera	-0.316		
Corixidae -0.155					
Coleoptera adults	-0.166				

Table 7. Organics and heavy metal chemistry results in $\mu g \cdot g^{-1}$ for sediments collected from the Red Deer River in November 1983.

	ABOVE DICKSON DAM	BELOW DICKSON DAM	ABOVE RED DEER	BELOW RED DEER	ABOVE DRUMHELLER	BELOW DRUMHELLER	AT EMPRESS
Branched hydrocarbons							
Mol. wt: 150-450	20 - 30	20 - 30	20 - 30		5 - 10	10 - 20	70 - 80
200-450				20 - 30			
Molecular sulphur - S_6	0.01 - 0.1	0.01 - 0.1	0.01 - 0.1		0.01 - 0.1		
S_7	0.01 - 0.1	0.01 - 0.1	0.01 - 0.1				
S_8	1 - 5	1 - 5	1 - 5	Trace	0.5 - 1	0.1 - 0.5	Trace
Carbonyl substituted hydroxyl Organics (mol. wt: 280)	1 - 5						
Alkyl substituted bibenzyl Organic $C_{16}H_{22}$ (mol. wt: 238)		1 - 5					
Tetrachloroethane 1,1,2,2		0.01 - 0.1	0.01 - 0.1			0.1 - 0.5	
Heneicosane			0.01 - 0.1		0.01 - 0.1	0.1 - 0.5	
Nonane				0.01 - 0.1			
Tricosane				0.01 - 0.1			
Bis(2-ethylhexyl)phthalate						0.5 - 1	
Octadecane						0.01 - 0.1	
Nonadecane						0.01 - 0.1	
Alkyl substituted naphthalene $C_{15}H_{18}$ (mol. wt: 198)						0.1 - 0.5	
Di-n-butylphthalate						0.1 - 0.5	
Heptadecane						0.1 - 0.5	
Lead (Pb)	10.0		11.7	12.0	11.3	19.0	
Copper (Cu)		9.4		8.8	12.6	6.1	24.6
Nickel (Ni)		19.6		22.1	19.9	18.5	33.9
Arsenic (As)		4.7		4.7	5.4	9.1	6.5
Cadmium (Cd)		0.29		0.16	0.16	0.16	0.47
Mercury (Hg)		0.03		0.02	0.03	0.02	0.06

In general, sediment metal concentrations were lowest below Drumheller and highest at Empress. The exception was arsenic, which was highest in concentration below Drumheller.

3.5 PRINCIPAL COMPONENTS ANALYSIS

Principal components analysis defined five to eight significant factors (eigenvalue greater than 1) for determining the variance in the chemistry data. The first three or four factors from annual and seasonal analyses are summarized in Table 8.

On an annual basis, the first factor included the variables dissolved inorganic carbon, alkalinity, bicarbonate, calcium, magnesium, and total dissolved solids and explained 29.5% of the variance. The second factor explained a further 22.7% of the variance and included particulate carbon and non-filterable residue. The third factor, defined by dissolved organic carbon, accounted for 10.2% of the variance. The fourth factor, defined by nitrate, nitrite, and ammonia, accounted for 7.4% of the variance.

On a seasonal basis, the results show the changing importance of different variables in explaining the variance. In the spring, the major ions were most important, followed by the particulate-related variables. Nitrogen forms took third place. In the summer, nutrients became most important, major ions dropping to secondary importance. Calcium carbonate interactions were next in importance. Principal components in the fall and winter were similar in status. The primary factors were carbon interactions and conductivity, the secondary factors were particulate-related, and the tertiary factors were nutrient-related.

Table 8. Results of principal components analysis of water chemistry from the mainstem sites on the Red Deer River.

FACTOR	EIGENVALUE	% OF VARIANCE	PRINCIPAL COMPONENTS COEFFICIENT > 0.8	COEFFICIENT 0.6-0.8
Annual				
1	9.43	29.5	DIC, Alk, HCO_3, Ca, Mg, TDS	Cond, Temp(-)
2	7.26	22.7	PC, NFR	TKN, TP, Fe
3	3.26	10.2	DOC	K, Phen, Phyt, COD
4	2.36	7.4	Nit, NO_2, NH_3	Si
Spring				
1	11.15	36.0	Cond, TDS, SO_4, HCO_3, Na, Mg, Alk	DIC, Fl
2	9.10	29.4	Fe, COD, TKN, NFR, PC, Turb	TP, PN, BOD, Ca(-)
3	3.46	11.2	NH_3, Nit, NO_2, K, Phen	DOC, Si, Cl
Summer				
1	11.70	39.0	NH_3, PP, TP, Nit	NO_2, TKN, Mg(-), pH(-)
2	3.55	11.8	Na, Cl, K	SO_4, Cond, Fl, Temp
3	3.43	11.4	HCO_3, Ca, Alk	Si
Fall				
1	10.75	30.7	HCO_3, Alk, Cond, DIC, TDS, Mg, Temp(-)	Ca
2	7.59	21.7	NFR, PP, Turb	Fe, SO_4, Cl, TP
3	3.89	11.1	DOC, Si(-), DKN	K, TKN, Na, Nit(-)
Winter				
1	9.86	32.9	HCO_3, Mg, Alk, Cond, TDS, DIC	Ca
2	6.27	20.9	PC, Fe, NFR, Na	DOC, Phyt
3	4.36	14.5	DKN, NH_3, TKN, OP, NO_2	

3.6 WATER QUALITY CRITERIA

Water quality objectives have been proposed for surface water (Alberta Environment, 1977), freshwater fish (Longmore and Stenton, 1981), and public water supply (Hamilton, 1983). Many objective concentrations are the same in the three guidelines (Table 9). In several cases the public water supply objectives are less stringent because these waters are processed before use. When objectives differ for surface water and freshwater fish, the former has lower requirements for arsenic, copper, manganese, selenium, and zinc. The latter has lower requirements for cadmium, phenolics, and phosphorus.

Hamilton (1983) discussed the freshwater fish and public water supply objectives relative to historical data within the Red Deer River basin. He concluded that despite the fact that the data showed that many objectives for freshwater fish were exceeded, the parameters of primary concern were temperature, dissolved oxygen, and un-ionized ammonia. The unreliability of some analyses in earlier years, particularly for metals, or the high natural concentrations of iron and manganese found in the basin may account for other parameters not meeting water quality objectives.

A comparison between water quality objectives and data collected from the Red Deer River and its tributaries during the study is presented in Tables 10a and 10b as percentage exceedances. Dissolved oxygen concentrations were above the minimum 5 $mg \cdot L^{-1}$ except in three tributaries: the Little Red Deer, Medicine, and Blindman rivers, during winter.

The bacteriological data were difficult to evaluate because the

Table 9. Comparison of water quality objectives for surface water, freshwater fish, and public water supply (units are $mg \cdot L^{-1}$, with exceptions noted).

	SURFACE WATER	FRESHWATER FISH	PUBLIC WATER SUPPLY
Arsenic	0.01	0.05	0.05
Beryllium		1.1	
Cadmium	0.01	0.001	
Chloride			0.005
Chromium			250
Coliforms-fecal[1]	0.05	0.05	0.05
-total[1]	200(1000)		1000
Copper	1000(5000)		5000
Fluoride	0.02	0.04	1.0
Iron	1.5		1.5
Lead	0.3	0.3	
Manganese	0.05	0.05	0.05
Mercury	0.05	1.0	0.05
Nickel	0.0001	0.0001	0.001
Nitrate		0.025	
Nitrite		6.8	10.0
Nitrogen (T)		0.6	1.0
Oxygen	1.0		
pH	5.0	5.0	
Phenolics	6.5-8.5	6.5-8.5	6.5-8.5
Phosphorus (as P)	0.005	0.001	0.002
Selenium	0.05	0.03	
Sulphate	0.01	0.05	0.01
Temperature°C			500
Zinc		22/25	
	0.05	0.3	5

Notes

[1] # per 100 mL - direct contact recreation (non-contact)

Table. 10a. Summary of percent exceedances of water quality criteria for data from the Red Deer River Basin (mainstream sitas).

WATER QUALITY PARAMETER	MAINSTEM SITES											
	DICKSON DAM		INNISFAIL	RED DEER		NEVIS	TROCHU	DRUMHELLER		FINNEGAN	JENNER	EMPRESS
	ABOVE	BELOW		ABOVE	BELOW			ABOVE	BELOW			
Surface Water Objectives												
Bacteriology-contact (non-contact)												
total coliforms	0	0	0	0	27	0	0	7	20	0	22(11)	8
fecal coliforms	27	0	9	7	47(7)	8	0	13	20	10	22(11)	15(8)
Dissolved oxygen	0	0	0	0	0	0	0	0	0	0	0	0
pH	0	0	13	27	47	20	31	40	40	27	0	0
Organic chemicals												
phenolics	7	7	13	7	13	20	8	13	13	13	14	13
Toxic chemicals												
arsenic	7	0		0								
cadmium	0	0		0								
chromium	0	0		0								
lead	7	0		0								
mercury	0	0		0								
selenium	0	0		0								
Inorganic chemicals												
copper	13	0		0								
fluoride	0	0	0	0	0	0	0	0	0	0	0	0
iron	27	13	27	27	21	13	23	33	54	33	60	60
manganese	13	14		13								
nitrogen	13	0	13	7	7	7	0	13	13	13	14	29
phosphorus	14	7	14	14	36	36	33	47	47	47	80	73
zinc	13	0		0								
Freshwater Fish Objectives*												
Beryllium	0	0		0								
Cadmium	20	7		13								
Copper	13	0		0								
Nickel	13	0		7								
Nitrate	0	0	0	0	0	0	0	0	0	0	0	0
Nitrite	0	0	0	0	0	0	0	0	0	0	0	0
Phenolics	Criteria less than detection											
Phosphorus	15	7	29	21	57	50	31	53	67	67	87	80
Temperature**									23.4°	23°	23°	23°
Public Water Supply*												
Chloride	0	0	0	0	0	0	0	0	0	0	0	0
Phenolics	20	20	33	40	60	47	46	47	47	40	57	40
Sulphate	0	0	0	0	0	0	0	0	0	0	0	0

* Parameters not previously evaluated or parameters with violations at a different objective concentration than previously evaluated
** Maximum measured value (°C)

Table 10b. Summary of percent exceedances of water quality criteria for data from the Red Deer River Basin (tributaries).

WATER QUALITY PARAMETER	TRIBUTARIES								
	RAVEN	LITTLE RED DEER	MEDICINE	BLINDMAN	THREEHILLS	KNEEHILLS	ROSEBUD	MATZHIWIN	ONETREE
Surface Water Objectives									
Bacteriology-contact (non-contact)									
total coliforms	18	0	9	0	0	0	15(8)	14	38
fecal coliforms	36(18)	7	9	8	0	25	31(8)	57	75(12)
Dissolved oxygen	0	7	13	7	0	0	0	0	0
pH	0	27	20	20	75	20	38	20	0
Organic chemicals									
phenolics	7	13	73	60	100	80	23	10	20
Inorganic chemicals									
fluoride	0	0	0	0	0	0	0	0	0
iron	33	40	60	47	50	60	54	40	80
nitrogen	7	23	33	64	100	100	31	10	40
phosphorus	14	36	57	73	100	60	77	90	100
Freshwater Fish Objectives*									
Nitrate	0	0	0	0	0	0	0	0	0
Nitrite	0	0	0	0	0	0	0	0	0
Phenolics	Criteria less than detection								
Phosphorus	36	36	93	93	100	80	77	100	100
Temperature**		25°	23°	23°			25°		
Public Water Supply*									
Chloride	0	0	0	0	0	0	0	0	0
Phenolics	33	87	100	100	100	100	85	60	100
Sulphate	0	0	0	0	0	0	0	10	10

* Parameters not previously evaluated or parameters with violations at a different objective concentration than previously evaluated
** Maximum measured value (°C)

main criterion was based on five samples taken in less than 30 days, and our sampling program did not meet this frequency requirement. On a relative basis, however, bacteria populations in the Red Deer River below Red Deer frequently exceeded the objective of 1000 per 100 mL total coliforms and 200 per 100 mL fecal coliforms for direct contact recreation such as swimming. Four tributaries: the Raven River, Rosebud River, Matzhiwin Creek, and Onetree Creek also has high bacterial counts. Non-contact recreation (e.g. boating) objectives were met in every case except for one sampling at three sites in the Red Deer River: below Red Deer, at Jenner, and at Empress and one sampling in each of the three tributaries: the Raven River, Rosebud River and Onetree Creek.

Phenolics objectives differed for surface water, freshwater fish, and public water supply, and the limits set were often exceeded. In fact, the objective for freshwater fish was less than the analytical detection limit. The least stringent objective was for surface waters, and samples from the Red Deer River exceeded this value (0.005 $mg \cdot L^{-1}$) only once or twice at most sites. Concentrations of phenolics in the tributary streams were above this value more frequently.

Samples to be analyzed for metals were only collected at those sites above and below the Dickson Dam and above the City of Red Deer. The site above the Dickson Dam was often the only one with metal concentrations exceeding the objectives. The major exception was the cadmium objective for freshwater fish (0.001 $mg \cdot L^{-1}$), which was exceeded at all three sites.

The objectives set for a number of criteria, notably pH, iron, manganese (only three sites measured), nitrogen, and phosphorus, were

exceeded at almost every site.

3.7 HISTORICAL AND LONG TERM TRENDS

In order to simplify the comparison between historical and study data, sites were combined and considered representative of three major river reaches: above Red Deer, from Red Deer to above Drumheller, and from above Drumheller to the mouth of the river. Also, to decrease the possibility of overemphasis on outliers and to reduce discrepancies resulting from seasonality of sampling, the median values for each reach were tabulated (Table 11). The historical data are those stored on NAQUADAT in the ten-year period from 1973 to 1982.

In comparing the historical and study data, a number of trends are apparent and similar in all three reaches (Table 11). First, concentrations of total coliforms, phenolics, several particulate-related variables (turbidity, total phosphorus, particulate phosphorus, particulate nitrogen, and total Kjeldahl nitrogen), total dissolved solids, and all of the major ions, as well as conductivity were lower during the study than historically. Conversely, concentrations of most dissolved nutrients (dissolved phosphorus and orthophosphorus) dissolved oxygen, biochemical oxygen demand, and phytoplankton were higher during this study, but ammonia and silica concentrations were low. Third, pH was higher and alkalinity lower than they were historically. Finally, although metal concentrations were measured only in the upstream reaches of the river during this study, except for zinc and arsenic, there was a general decrease in concentrations when compared to historical values.

Long-term trends were investigated by reviewing average annual

Table 11. Comparison of median values from historical (1973-1982) and study data from mainstem river sites on the Red Deer River (units are $mg \cdot L^{-1}$ with exceptions noted).

	ABOVE RED DEER		RED DEER TO DRUMHELLER		BELOW DRUMHELLER	
	Historical	Study	Historical	Study	Historical	Study
Dissolved oxygen	9.9	10.9	8.4	9.7	9.0	9.4
COD	4.8	8.9	11	10.7	2.0	19.7
BOD	L1.0	L1.0	1.0	1.5	1.2	1.8
Turbidity[1]	4.0	3.9	2.8	2.5	23	9.5
NFR	9	10	10	10	49	26
TDS	243	192	302	199.5	290	219
Na	7.8	6	12.8	11	20	18
Ca	54.1	46	58	44	47.2	40
Mg	18.6	14	19.8	14	16.8	14
K	1.2	1.1	1.7	1.4	2.1	1.5
Cl	1.1	L1	2.8	2	2.8	2
SO_4	41	31	44.8	30	49	45
Fl	0.16	0.14	0.20	0.15	0.15	0.15
Fe	0.12	0.15	0.11	0.13	0.62	0.28
Conductivity[2]	422	361	480	377	414	395
pH	8.1	8.4	8.1	8.5	8.2	8.4
Alkalinity	176	158	204	161	162	162
DOC	2.6	2.6	4.7	4.5	4.0	4.4
DIC	38	38		37.5	33	39
PC	0.30	0.26	0.53	0.57	1.3	1.24
TP	0.058	0.018	0.246	0.036	0.061	0.054
DP	0.004	0.008	0.016	0.020	0.008	0.016
OP	L0.002	0.008	0.003	0.012	0.003	0.011
PP	0.011	0.007	0.020	0.008	0.035	0.020
Si	5.5	4.8	2.4	2.1	4.3	1.5
Phenolics	0.002	L0.002	0.003	L0.002	0.002	L0.002
Coliforms-total[3]	48	13	81	52	43	20
-fecal[3]	10	5	28	11	5	10
PN	0.05	L0.01	0.08	0.035	0.168	0.08
TKN	0.44	0.190	0.56	0.320	0.700	0.440
DKN		0.160		0.270		0.280
NO_3+NO_2	L0.1	0.024	L0.1	0.003	0.02	0.005
NO_2	L0.1	L0.001	0.076	L0.001	L0.1	L0.001
NH_3	L0.2	0.010	0.3	0.012	0.2	0.012
Phytoplankton[4]	0.005	0.8		1.7	0.0055	2.6
Hg	L0.0001	L0.0001	0.0000		L0.0001	
Co	0.0018	L0.001	0.0010		0.0015	
Cu	0.0030	0.002	0.0012		0.0020	
Ni	0.0095	0.005	0.0100		0.0095	
Cd	L0.0010	L0.001	L0.0010		L0.0010	
Pb	L0.003	L0.003	L0.0030		L0.004	
Zn	0.015	0.0035	0.0312		0.025	
Al	0.093	0.050	0.12		0.74	
Be		L0.001	0.0080		L0.005	
Mn	0.0140	0.012			0.0135	
Cr		0.003				
As	0.0003	0.0006			0.0005	
Se		L0.0002				
Va		0.003				
Mo	0.0092	L0.001	0.0015		0.0030	

[1] JTU
[2] $\mu S \cdot cm^{-1}$
[3] # per 100 mL
[4] $mg \cdot m^{-3}$ chlorophyll a

L = less than

values from data collected at the regular monitoring sites at Red Deer, Drumheller, and Bindloss (Table 12). Because seasonal trends would bias an annual value, only years with 10 - 12 months of data were compared. Few trends were obvious; however, the variability from year to year was evident. Trends over three to four years indicated that sodium, total phosphorus, and particulate phosphorus concentrations increased at Red Deer, and particulate nitrogen concentrations decreased at Drumheller. The most apparent trend, however, was a reduction in conductivity. This was shown in data from both Drumheller and Bindloss.

4.0 DISCUSSION AND CONCLUSIONS

4.1 BASELINE CONDITIONS

Many of the objectives of the intensive monitoring program of the Red Deer River were related to the establishment of a reliable database. These baseline conditions indicated the current status of the river basin, including the effect of development, and form a basis for comparison for any future effects or development.

The predominant factors determining the variability in water quality in the Red Deer River, on an annual basis, are basin geology, discharge, and to a lesser extent, organics and nutrients. The natural solution of salts and minerals from rocks and soils in the drainage basin dictate the conductivity, alkalinity, and concentration of major ions typical for the basin. The variation in discharge over the year will affect both the variation in these factors, as well as the concentration of particulates that the river can transport. Organics and nutrients were of tertiary importance in explaining variations in water chemistry

Table 12. Comparison of mean annual water chemistry data at long-term monitoring sites from 1973 to 1983 with study data from the Red Deer River (units are $mg \cdot L^{-1}$, with exceptions noted).

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	Study
ABOVE RED DEER												
Turbidity[1]					24.1	5.6	5.2	15.9	6.8	11.2	9.4	
NFR						29	8	9	27	16	23	31
Na	8					7	6	7	7	8	9	8
Ca	58					54	53	53	51	56	53	46
Mg						18	18	20	18	18	17	14
K	2.0					1.9	1.2	1.2	1.5	1.7	1.5	1.6
Cl	2					1	1	1	2	2	2	1
SO_4						35.3	39.7	39.2	33.5	37.2	33.2	30.1
Fl							0.12	0.13	0.16	0.14	0.13	0.14
Conductivity[2]	395					407	442	437	441	410	392	368
pH[3]	8.1					8.1	8.1	8.1	8.1	8.0	8.1	8.5
Alkalinity	175								188	192	183	166
DOC						4.4	2.6			5.0	4.0	3.8
PC							0.42	0.52	1.22	0.63	0.92	1.23
TP						0.062	0.017	0.027	0.034	0.042	0.034	0.043
DP							0.006				0.005	0.014
PP							0.010	0.021	0.027	0.028	0.024	0.031
Si	5.9										5.1	4.3
PN							0.058	0.090	0.090	0.053	0.087	1.981
NIT						0.137	0.069				0.060	0.048
AT DRUMHELLER												
Turbidity[1]	89.2					38.4	23.7	73.8	53.9	24.2	23.2	46.5
NFR						81	76	375	110	74	50	121
Na	20					14*	15	16	18	15	20	16
Ca	55					56	49	51	48	53	50	41
Mg						18	18	18	17	18	17	14
K	2.2					3.0	2.5	2.0	3.0	3.0	2.6	2.2
Cl	2					9*	3	3	3	4	3	2
SO_4						39.8	44.8	44.3	38.8	40.6	45.5	36.3
Fl							0.14	0.15	0.14	0.15	0.13	0.15
Conductivity[2]	438					425*	442	486	448	427	427	387
pH[3]	8.1					8.2	8.1	8.1	8.2	8.0	8.2	8.5
Alkalinity	185								181	199	186	166
DOC						9.2	3.8			6.7	5.0	5.6
PC							1.63	1.59	2.67	2.01	1.19	1.86
TP						0.129	0.110	0.248	0.154	0.205	0.074	0.072
DP							0.043				0.029	0.027
PP							0.067	0.221	0.097	0.121	0.045	0.038
Si	4.7										3.3	2.6
PN							0.232	0.510	0.358	0.224	0.155	0.214
NIT						0.513	0.186	0.400			0.193	0.093

Table 12. [Continued]

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	Study
AT BINDLOSS												
Turbidity[1]	57.0	64.3	113.8	48.7	81.1	187.1	62.6	127.7	52.3	52.5	61.2	112.5
NFR	286		167	119	280	444	139	337	135	199	349	398
Na	26	28	33	26	25	27	30	30	25	26	28	28
Ca	52	55	55	52	51	56	50	53	53	55	50	43
Mg				22	21	21	20	21	20	21	19	15
K	3.3	2.8	3.4	2.6	2.1	2.8	3.1	2.7	2.8	3.2	3.3	3.0
Cl	3	4	9	5	4	5	5	5	5	6	5	4
SO_4			81.4	76.3	67.4	67.3	72.1	69.6	58.8	62.4	69.7	65.2
Fl		0.15	0.10	0.13	0.17	0.15	0.15	0.16	0.14	0.16	0.13	0.16
Conductivity[2]	469	487	541	506	475	510	535	548	510	510	479	461
pH[3]	8.2	8.1	8.0	8.0	8.2	8.1	8.0	8.2	8.2	8.0	8.1	8.3
Alkalinity	169	193	202	194	175				198	221	179	172
DOC						6.4	4.3			5.6	5.3	5.6
PC						5.59	2.79	4.88	3.24	4.00	5.16	3.70
TP		0.129	0.152	0.126	0.135	0.161*	0.135	0.303	0.145	0.167	0.310	0.185
DP				0.016		0.017	0.028				0.016	0.014
PP				0.110		0.143*	0.108	0.294	0.133	0.152	0.296	0.111
Si	4.9	5.2	4.5	4.0	3.7						4.0	3.6
PN						0.687*	0.303	0.424	0.353	0.478	0.523	0.804
NIT					0.162	0.372	0.303				0.206	0.142

[1] JTU
[2] $\mu S.cm^{-1}$
* One outlier removed from calculation of mean

over the year. In summer, however, nutrients were the most important factor.

Seasonal changes in many of the water chemistry variables were similar to those in the Bow, Oldman, and South Saskatchewan rivers (Cross et al., 1986; Charlton et al., 1986). This is not surprising because the Red Deer River is subject to similar climatic conditions as the other rivers in the South Saskatchewan River Basin. However, in many cases, seasonal variability in the water quality of the Red Deer River followed that of the Oldman and South Saskatchewan rivers more closely than that of the Bow River. The Oldman/South Saskatchewan River system had less flow regulation and was less affected by nutrient inputs than was the Bow River.

The particulate-related variables such as turbidity, and total phosphorus and particulate carbon concentrations showed the erosive effect of high flows with a seasonal pattern of high peak values similar to that seen in the relatively unregulated Oldman River. The effect of the extensive badlands area along the Red Deer River was shown in the longitudinal increase in these variables. Although a similar increase was found in the South Saskatchewan River, it was much less pronounced (Cross et al., 1986).

The effect of basin geology and irrigation return flow is reflected in the higher alkalinities and intermediate conductivities in the Red Deer River compared to the Bow, Oldman, and South Saskatchewan rivers. Average alkalinity values are 165 $mg \cdot L^{-1}$ $CaCO_3$ for the Red Deer River and 123, 141, and 127 $mg \cdot L^{-1}$ $CaCO_3$ for the Bow, Oldman, and South Saskatchewan rivers, respectively. The corresponding

conductivity values are 392 (Red Deer River), 366 (Bow River), 413 (Oldman River), and 413 (South Saskatchewan River) $\mu S \cdot cm^{-1}$.

In terms of nutrients, concentrations of silica and dissolved carbon forms were higher in the Red Deer River than in the other rivers in the basin. Silica concentrations averaged 3.4 $mg \cdot L^{-1}$ in the Red Deer River and 3.2, 2.3, and 2.0 $mg \cdot L^{-1}$ in the Bow, Oldman, and South Saskatchewan rivers, respectively. Corresponding dissolved inorganic carbon concentrations were 40.4 $mg \cdot L^{-1}$ versus 28.8, 32.5, and 29.2 $mg \cdot L^{-1}$, and dissolved organic carbon concentrations were 5 $mg \cdot L^{-1}$ versus 2, 3, and 3 $mg \cdot L^{-1}$, respectively (Cross et al., 1986).

Concentrations of nitrates in the Red Deer River were similar to those in the Oldman River at its confluence with the Bow River. On average, however, nitrate concentrations were much lower in the Red Deer River (0.081 $mg \cdot L^{-1}$) than in the Bow, Oldman, or South Saskatchewan rivers (0.652, 0.137, and 0.515 $mg \cdot L^{-1}$, respectively).

Average dissolved phosphorus concentrations in the Red Deer River (0.018 $mg \cdot L^{-1}$) were generally lower than those in the Bow, Oldman, or South Saskatchewan rivers (0.113, 0.045, and 0.054 $mg \cdot L^{-1}$, respectively), and seasonal patterns were similar to the Oldman River at its confluence with the Bow River (Cross et al., 1986).

The Red Deer River carried a much lower annual dissolved phosphorus load than either the Bow or Oldman rivers. The point loading 35 tonnes from Red Deer of was comparable to that of Medicine Hat. However, as the major discharge into the Red Deer River, it represented only 36% of the total loading, compared to 91% from Calgary into the Bow

River (Cross et al., 1986) and 78% from Lethbridge into the Oldman River. In contrast, upstream sources represented 16% of the total loading versus 2% for the Bow River and 17% for the Oldman River, whereas tributaries and irrigation return flows represented 44% (Red Deer River) versus 5% (Bow River) and 3% (Oldman River).

Standing crops of epilithic algae showed seasonal patterns similar to those in the remainder of the South Saskatchewan River Basin, concentrations being similar to those in the Oldman and South Saskatchewan rivers. The average value for the Red Deer River was 49 $mg \cdot m^{-2}$ chlorophyll *a* compared to 141 $mg \cdot m^{-2}$ chlorophyll *a* in the Bow River, and 51 and 46 $mg \cdot m^{-2}$ chlorophyll *a* in the Oldman and South Saskatchewan rivers, respectively (Charlton et al., 1986).

The longitudinal zonation of benthic invertebrate communities found during the spring survey is typical for a river that crosses different ecoregions. Culp and Davies (1982) attribute similar factors in the Oldman/South Saskatchewan River system to increases in algal biomass, plant nutrients, and water temperature.

4.2 EFFECT OF CITIES AND TRIBUTARIES

Typical of municipal effluent, sewage from the City of Red Deer affected the water chemistry of the Red Deer River by increasing the levels of nutrients and coliform bacteria. This effect was also seen as increases in algal and zoobenthic population densities; it was reduced at the downstream sites.

The effect of the City of Drumheller was less than that of Red Deer and was complicated by several factors. First, several tributaries

enter the Red Deer River just upstream of Drumheller. Although these streams run primarily during the spring runoff and following storm events, they appeared to affect the river above Drumheller in a manner typical of municipal effluent. This may have resulted from the input of municipal and agricultural effluents within their drainage basins. Second, the historical presence of coal mines in the area may have affected the river at the site below Drumheller. Concentrations of sediment organics and some metals increased whereas benthic algal and benthic invertebrate populations decreased.

The effects of increased algal standing crops were shown as diurnal fluctuations of dissolved oxygen. These fluctuations below Red Deer were similar to those on the Bow River below Calgary (Cross et al., 1986), although the amplitude was smaller. The pattern of diurnal dissolved oxygen fluctuations at Drumheller indicated an effect from the tributary streams at Drumheller.

4.3 WATER QUALITY CRITERIA

Comparison of data to water quality objectives for surface water, freshwater fish, and public water supply indicated several areas of concern. First, bacteriological data, evaluated strictly on the basis of percentage exceedances, indicated that contact recreation is generally inadvisable, particularly around Red Deer, Drumheller, and in the lower reaches of the Red Deer River. The objective for non-contact recreation was exceeded in a few cases, but, water quality is generally adequate for such purposes along the length of the river. A more detailed data set is necessary to make the comparison between river water quality and the

Alberta Surface Water Quality Objectives.

A second area of concern was concentrations of dissolved oxygen in the winter. Results from this study indicate that levels remained satisfactory in the river in the winter of 1984, although upstream tributary streams showed a natural oxygen depletion during the winter.

Concentrations of metals exceeded objectives in several cases. This occurred most frequently above the Dickson Dam. These occurrences may be related to sediment particles being carried during high flow periods. The fact that the cadmium criteria for freshwater fish was exceeded at all three sites indicates that more detailed sampling may be required.

Some of the criteria may be naturally exceeded within the Red Deer River Basin. This would certainly be the case for iron and manganese, the sources of which are likely to be natural weathering of rocks and soils. Similarly, although nitrogen and phosphorus, and indirectly pH, would be affected by eutrophication, natural background levels in the rivers also exceeded objectives. For example, the natural suspended sediment load from erosion would represent a major contribution to total nutrient concentrations.

The objective concentration for phenolics is different for each set of criteria. Natural levels, however, may be higher than the objectives as a result of the high organic loading from the upstream tributaries. Water supply considerations for phenolics are related to the aesthetic values of taste and odour. Phenolic compounds are not toxic until much higher concentrations are encountered.

4.4 DOWNSTREAM EFFECTS OF THE DICKSON DAM

Only a preliminary assessment of the downstream effects of the Dickson Dam was possible from the data base collected for this report. The local effect of the installation of the Dickson Dam was readily apparent after comparison of the data from above and below the dam. It was also reflected in data collected from sites down the length of the river when compared to historical data.

The settling of particles through sedimentation in the reservoir reduced the concentrations of the particulate-related variables (turbidity, total and particulate phosphorus, particulate nitrogen, and total Kjeldahl nitrogen) and metals. Release of water from the dam would also account for the very high peaks in concentrations of the particulate-related variables as a result of downstream scouring when flow was increased rapidly.

In January and February 1984, the dam was operated so as to increase winter dissolved oxygen concentrations by increasing flow from 8 to 16 $m^3 \cdot sec^{-1}$. This was effective in keeping concentrations above 5 $mg \cdot L^{-1}$ throughout the mainstem despite the input of low concentrations of oxygen from the upstream tributaries. Continued monitoring is warranted to determine whether this will be effective in other winters because Grant (1973) recommended a winter flow of 22.6 $m^3 \cdot sec^{-1}$ (800 cfs).

The first year of benthic invertebrate data indicated that a significant disturbance occurred after the Dickson Dam became operational. The longitudinal pattern should remain basically the same in the spring and fall, although the numbers and a few species might be

different. The longitudinal pattern in spring was typical of a river crossing several ecological zones, municipal disturbances occurring at Red Deer and Drumheller. Following the operation of the dam throughout the summer, benthic invertebrate populations at the site below the dam were very different from all the other sites, and indeed, the typical transitional pattern was disturbed. A full analysis of the impact of the Dickson Dam on the water quality and zoobenthos of the Red Deer River is available in Shaw and Anderson (1991).

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